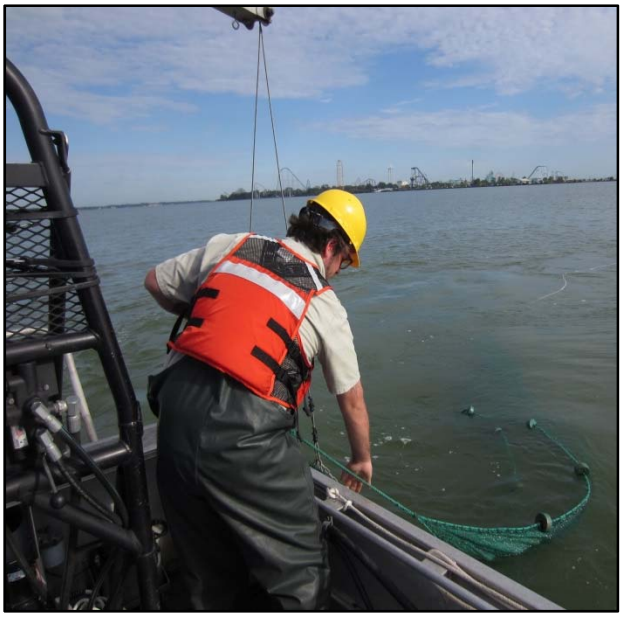
U. S. Fish and Wildlife Service

Early Detection and Monitoring of Non-Native Fishes and Benthic Macroinvertebrates in Lake Erie, 2016



March 2017

Anjanette Bowen, Andrew Briggs, Patricia Thompson, and Matthew McLean

U. S. Fish and Wildlife Service
Alpena Fish and Wildlife Conservation Office
480 West Fletcher Street
Alpena, Michigan 49707

Theodore Lewis, Sandra Keppner, Robert Haltner, and Jacob Cochran

U. S. Fish and Wildlife Service
Lower Great Lakes Fish and Wildlife Conservation Office
1101 Casey Road
Basom, New York 14013

Suggested citation:
U. S. Fish and Wildlife Service. 2017. Early detection and monitoring of non-native fishes and benthic macroinvertebrates in Lake Erie, 2016. U. S. Fish and Wildlife Service, Alpena Fish and Wildlife Conservation Office, Alpena, Michigan and U. S. Fish and Wildlife Service, Lower Great Lakes Fish and Wildlife Conservation Office, Basom, New York. 88 pp.

On the cover:
(Left photo): Benthic trawling conducted in Sandusky Bay to sample for adult and juvenile fishes. Photo credit: A. Bowen, USFWS. (Right photo): Night ichthyoplankton sampling in Buffalo/upper Niagara River using a bongo net to collect larval fish. Photo credit: M. Paufve, USFWS.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS 4
EXECUTIVE SUMMARY 5
INTRODUCTION 7
STUDY AREAS 9
METHODS 11
Adult/Juvenile Fish Sampling 11
Ichthyoplankton Sampling 12
Benthic Macroinvertebrate Sampling 13
Data Analysis 14
RESULTS 15
Adult/Juvenile Fish Sampling 15
Ichthyoplankton Sampling 20
Benthic Macroinvertebrate Sampling 22
DISCUSSION 22
REFERENCES 24
TABLES 30
FIGURES 43
APPENDICES 61
Appendix A. Pilot Study for the Early Detection of Non-Native Fishes in Presque Isle Bay, Erie, Pennsylvania 61
Appendix B. Ichthyoplankton Collection Methodology Pilot Study 67
Appendix C. Exploring Methods to Increase Detection Efficiency 75

ACKNOWLEDGEMENTS

We thank our partners and staff who assisted with planning, sampling, and analysis associated with this effort including: S. Hensler, S. Gambicki, M. McLean, J. Lajavic, J. Loughner, K. Genther, P. Wigren, L. Adams, A. Gereau II, and C. Olds of USFWS Alpena FWCO; J. Lang, M. Rosten, M. Caldwell, H. Himes, and S. Furgal of USFWS Lower Great Lakes FWCO; E. Roseman, S. Ireland, D. Bowser, and S. Provo of USGS Great Lakes Science Center; J. Hoffman of USEPA Mid-Continent Ecology Division; J. Schlosser of USFWS Ashland FWCO; and a number of volunteers. This project was funded in part by the Great Lakes Restoration Initiative.

EXECUTIVE SUMMARY

The Laurentian Great Lakes have encountered numerous aquatic non-native and invasive species introductions since Europeans settled in North America (Mills et al. 1994). The impact of aquatic invasive species (AIS) on the Great Lakes has been widely documented by the scientific community (Leung et al. 2002; Mills et al. 1993; Rosaen et al. 2012). Despite increasing regulations aimed at reducing the likelihood of the introduction and spread of AIS into the Great Lakes, there remains a need to monitor for and detect new species before they become established. This is especially true given the costs and difficulty of attempting to control or eradicate a non-native species once it is established (Trebitz et al. 2009). If a non-native species is detected prior to becoming well established, rapid response decisions can be made in an effort to eradicate or control the species from further spread. Furthermore, continuous monitoring also allows resource managers to document the baseline community, look at historical data and assess the impact of future invasions (Trebitz et al. 2009).

This report summarizes the 2016 efforts for early detection of non-native fishes and select benthic macroinvertebrates in Lake Erie as implemented by the U. S. Fish and Wildlife Service (USFWS), Alpena Fish and Wildlife Conservation Office and the Lower Great Lakes Fish and Wildlife Conservation Office. Multiple sampling locations in Lake Erie were selected due to their high likelihood of new non-native species introductions according to a risk-based analysis of how those organisms may spread to the area, also known as a vector risk analysis (USFWS 2014a). Lake Erie sampling locations included the Detroit River (MI/ON), Maumee Bay (OH/MI), Sandusky Bay (OH), and Buffalo/upper Niagara River (NY). Within survey locations, sites were stratified by suitable gear type according to sampling depth and randomly selected from all sites meeting each depth criteria (USFWS 2014a). Gear used to target juvenile and adult fish were utilized at each location and included day/night electrofishing, paired fyke nets, bottom trawls, and minnow trap arrays. Gear used to target larval fish were deployed at three locations and included bongo nets and light traps. Benthic macroinvertebrates were sampled at two locations with benthic sled or Hester Dendy colonization samplers and amphipod traps.

Blueback Herring *Alosa aestivalis* were captured in the upper Niagara River during juvenile and adult fish sampling during 2016, which constitutes an expansion of the non-native range of this species into western New York (USGS 2017). No other previously undocumented juvenile or adult non-native species were detected in Lake Erie. A total of 18,431 juvenile and adult fish were collected as a result of sampling at Lake Erie locations during 2016. Crews captured 43 species and 2,928 fish in the Detroit River; 38 species and 6,830 fish in Maumee Bay; 32 species and 4,116 fish in Sandusky Bay; and 44 species and 4,557 fish in Buffalo/upper Niagara River. Previously established non-native species were captured often during sampling (e.g., Alewife *Alosa pseudoharengus*, Bigmouth Buffalo *Ictiobus cyprinellus*, Common Carp *Cyprinus carpio*, Goldfish *Carassius auratus*, Rainbow Smelt *Osmerus mordax*, Round Goby *Neogobius*

melanostomus, Rudd *Scardinius erythropthalmus*, Tubenose Goby *Proterorhinus semilunaris*, and White Perch *Morone americana*).

A total of 9,439 larval fish were collected at Lake Erie locations during 2016 and identified to the lowest taxonomic level possible. Crews captured 6,894 fish from Maumee Bay comprised of 11 species and eight additional genus groupings, 2,326 fish from Sandusky Bay comprised of nine species and seven additional genus groupings, and 219 fish from Buffalo and the upper Niagara River comprised of 15 species and one additional genus grouping. No previously undocumented species were detected as a result of larval fish sampling in Lake Erie. Previously established non-native species including Alewife, Common Carp, Rainbow Smelt, Round Goby, and White Perch were collected.

Macroinvertebrate sampling was conducted at two locations on Lake Erie in 2016. No previously undocumented species were detected. At least 12 species and 4,065 organisms were detected at the Buffalo/upper Niagara River sampling location. Results for Maumee Bay are pending and expected in April 2017.

Using rarefaction analysis on data collected from 2013-2016, the current detection rate for juvenile and adult fish at locations sampled ranged from 45-96% of the estimated species assemblages (Chao et al. 2009). For the sampling regime to be most effective, species detection efficiency must be high (e.g., 95%) enough to detect rare species present at low abundances (Hoffman et al. 2011). In 2016 one new non-native species, the Blueback Herring, was detected in Buffalo; no new non-native species were detected in the other three sample areas. This reinforces the critical nature of an early detection monitoring program in 2017 as an essential part of non-native and invasive species management for Lake Erie.

INTRODUCTION

Establishment of aquatic non-native species in the Great Lakes has caused major ecological and economic impacts (Mills et al. 1993; Vanderploeg et al. 2002; Rosaen et al. 2012; Rothlisberger et al. 2012). The cost of aquatic non-native species to the Great Lakes Region, whose fishery is valued at $7 billion (ASA, 2008), is well over $100 million annually (Rosaen et al. 2012). An estimated $138 million is spent each year mitigating the damages generated by ship-borne non-native species, a single introduction vector representing only a portion of invasive species present in the Great Lakes (Rothlisberger et al. 2012). Non-native species have entered the Great Lakes through a variety of vectors including ballast water from shipping vessels, canals, aquarium releases, bait release, and intentional stocking by management agencies (Mills et al. 1994). The Great Lakes currently contain at least 182 identified nonindigenous aquatic species (Ricciardi 2006), 130 of which are present in Lake Erie (Great Lakes Aquatic Nonindigenous Species Information System, GLANSIS, NOAA 2016).

The impacts of historical non-native introductions in Lake Erie have been widely documented. Sea Lamprey *Petromyzon marinus* presumably entered Lake Erie and spread to the upper Great Lakes by means of the Welland Canal (Aron and Smith 1971). Ecological and economic impacts from the lamprey invasion have been observed as losses in commercial and recreational fishing income, tourism, and costs associated with control measures (Smith and Tibbles 1980; Jones 2007). The United States and Canada spend over $20 million per year on sea lamprey control measures alone (Dissanayake et al. 2016). Zebra mussels *Dreissena polymorpha* and quagga mussels *D. bugensis* have altered trophic dynamics by competing for resources with native bivalves, promoting conditions favorable to harmful algal blooms, and concentrating energy resources into benthos causing oligotrophication (Vanderploeg et al. 2002). Additionally, these mussels negatively impact industries such as power plants and water treatment facilities (Lovell et al. 2006). Total economic costs of zebra mussels are estimated around $5 billion (Lovell et al. 2006). The introduction of Rainbow Smelt *Osmerus mordax* has caused declines in recruitment of native planktivores such as Lake Whitefish *Coregonus clupeaformis* and Lake Herring *Coregonus artedi* (Evans and Loftus 1987), and the subsequent spread of Alewife *Alsoa pseudoharengus* has been linked to reproductive failures in Lake Trout *Salvelinus namaycush* and Atlantic Salmon *Salmo salar* (Fisher et al. 1996).

Great Lakes waterways continue to face the threat of new invasions. Some non-native species have been documented as present but are not yet abundant, while others are not present but pose a high risk of invasion. Currently, the most notable potential invaders of the Great Lakes basin are four infamous species of Asian Carp – Bighead Carp *Hypophthalmichthys nobilis*, Silver Carp *Hypophthalmichthys molitrix*, Grass Carp *Ctenopharyngodon idella*, and Black Carp *Mylopharyngodon piceus*. Bighead and Silver Carp are large, planktivorous fish that, once established, have been reported to dominate fish assemblages (represent as much as 97% of total fish biomass in portions of the Mississippi River basin; MICRA 2002) and alter the structure and

species composition of native plankton communities (Laws and Weisburd 1990; Vörös et al. 1997; Stone et al. 2000). Grass Carp have been captured at isolated locations within Lake Erie but are not known to be abundant (Baerwaldt et al. 2013; USGS 2017). Nonetheless, natural reproduction of Grass Carp has recently been documented within the Lake Erie watershed (Chapman et al. 2013; Embke et al. 2016). This species feeds on submerged aquatic macrophytes and may threaten coastal wetlands which are important spawning and rearing habitats for many species (Chapman et al. 2013). There have been isolated catches of adult Bighead Carp in Lake Erie including two captures near Sandusky in Ottawa County Ohio in 1995 and 2000, and a capture west of Point Pelee in Ontario, Canada in 2000 (Morrison 2004). There has been no evidence of establishment. Bighead and Silver Carp are known to inhabit rivers that indirectly connect to Lake Erie tributaries during high water events (GLMRIS 2011). Populations of Silver Carp and Bighead Carp have rapidly expanded in the Mississippi River and the Illinois River and are moving closer towards Lake Michigan and the Great Lakes (Chick and Pegg 2001). In an attempt to protect the ecological and economic value of the Great Lakes region, Federal and state agencies plan to spend over $25 million in Asian Carp prevention and research in the coming year alone (ACRCC 2016). Asian Carp represent just a few of the potential invaders threatening the Great Lakes resulting in costly prevention measures. Furthermore, many additional species have been identified as posing a high risk of introduction through ballast water, the aquarium trade, and other vectors outside of immediately connected waterways (Kolar and Lodge 2002; GLANSIS Watchlist, NOAA 2016). Minimizing additional introductions of non-native species to the Great Lakes has become increasingly important given the significant impacts existing invaders have had on this ecosystem.

The Great Lakes Restoration Initiative (GLRI 2014) is a historic initiative aimed at restoring and protecting the integrity of the Great Lakes that was first implemented in 2010. GLRI is a plan of action that recognizes regulation and education alone are not enough to protect and restore the Great Lakes. GLRI includes a number of focus areas that address Great Lakes issues including an invasive species component. Within the GLRI invasive species focus area there is a charge to "conduct early detection and monitoring activities'. Preventing the transfer of a new species to an ecosystem is ultimately the most effective tool to keep non-native species from becoming invasive. When complete prevention is not possible, the next most effective option is monitoring for the arrival of new species and controlling their spread before they become widespread (USEPA 2008; Trebitz et al. 2009, Hoffman et al. 2016). In 2012 the Great Lakes Water Quality Agreement (1987) was renewed and included a number of annexes to address issues in the Great Lakes. One such is Annex 6, an Aquatic Invasive Species Annex whose purpose is to "... *establish a binational strategy to prevent the introduction of Aquatic Invasive Species (AIS), to control or reduce the spread of existing AIS, and to eradicate, where feasible, existing AIS within the Great Lakes Basin Ecosystem".* Included in the Programs and Measures component of the Annex is the task to develop and implement an early detection and rapid response initiative that: "(a) develops species watch lists; (b) identifies priority locations for surveillance; (c) develops

monitoring protocols for surveillance". Within science efforts charged by the Annex is the need for "*development and evaluation of technology and methods, including genetic techniques, that improve the ability to detect potential AIS at low levels of abundance*".

The U. S. Fish and Wildlife Service (USFWS) developed a strategic framework for the early detection of non-native fishes and select benthic macroinvertebrates in the Great Lakes (USFWS 2014c). Fish and Wildlife Conservation Offices (FWCOs) throughout the Great Lakes lead and coordinate this program. This report describes the efforts devoted to the early detection of non-native fishes and benthic macroinvertebrates at four high risk locations across the Lake Erie basin in 2016, and is a continuation of coordinated efforts initiated in 2013 (USFWS 2016).

STUDY AREAS

Lake Erie study areas were chosen through the use of a vector risk analysis for species at risk to become introduced into the Great Lakes. Study areas, sampling gears, and sampling targets were identified in the *Lake Erie Implementation Plan for the Early Detection of Non-Native Fishes and Select Benthic Macroinvertebrates* (USFWS 2014a).

Four study areas across two USFWS regions, the Midwest and Northeast, were sampled in 2016. The Detroit River, Maumee Bay, Sandusky Bay, and Buffalo/upper Niagara River were identified as high risk locations for introduction of non-native species (Figure 1).

Detroit River—The Detroit River is the lower part of a connecting channel between lakes Huron and Erie and serves as the international border between the United States (Michigan) and Canada (Ontario) along its entire 44 km length. The Detroit-Windsor area is densely populated with a high amount of recreational angling and boating. The Detroit River is also a major shipping port and the surrounding area is highly industrialized. The river is an important navigational shipping route connecting lakes Michigan, Huron, and Superior (the upper Great Lakes) with lakes Erie and Ontario (the lower Great Lakes) and the St. Lawrence Seaway. The Detroit River was designated an Area of Concern (AOC) as part of the Great Lakes Water Quality Agreement of 1987 due to pollution. Sections of the Detroit River contain critical fish and wildlife habitat. In 2001, the Detroit River International Wildlife Refuge was founded to protect some of these important habitats. Recently, many agencies have focused their efforts on restoring the biological integrity of the river. The study area encompassed U. S. waters in Michigan and Canadian waters in Ontario, and extended the length of the river. The total surface area of the sampling location was approximately 120,952 ha.

Maumee Bay, Michigan/Ohio—Maumee Bay is located in the southwest corner of Lake Erie's western basin near the city of Toledo, Ohio, and includes both Michigan and Ohio waters of Lake Erie. Toledo, the fourth largest city in Ohio, is a major commercial shipping port receiving high levels of ballast water. Maumee Bay supports tourism, including recreational boating and

fishing. The Maumee River, the largest tributary to Lake Erie, was named an AOC as part of the Great Lakes Water Quality Agreement of 1987 due to sediment contamination and agricultural runoff. The river originates at the confluence of the St. Joseph and St. Mary's rivers near Fort Wayne, Indiana, and represents a potential pathway for non-native species to enter Lake Erie from the Mississippi River basin via Eagle Marsh (GLMRIS 2011). In an effort to help prevent the spread of non-native species between these basins, a berm was constructed at Eagle Marsh in 2015. The study area encompassed the Maumee River approximately 1 km upstream from the river mouth in Maumee Bay, and extended northeast approximately 26 km to a parallel boundary extending north from the outer boundary of Cedar Point National Wildlife Refuge northwest to Grand View, Michigan. Maumee Bay waters within Michigan and Ohio were within the study area, and the total surface area of the survey location was approximately 9,200 ha.

Sandusky Bay—Sandusky Bay is located in northern Ohio on Lake Erie near the cities of Sandusky and Port Clinton. The bay is shallow and fed by the Sandusky River. A hydrologic connection between the Mississippi River basin and the Sandusky River via Grand Lake and the St. Mary's River makes this a high-risk pathway for introductions of non-native species to Lake Erie (GLMRIS 2011). Sandusky maintains a port for maritime commerce. The study area encompassed the eastern boundary of Muddy Creek Bay at Peach Island and Canvasback Point, and extended east approximately 24 km to the easternmost boundary of Cedar Point. The total surface area of the survey location was approximately 13,500 ha.

Buffalo/upper Niagara River—Buffalo, New York and its surrounding waterways are industrialized areas that have historically been important to shipping within the Great Lakes. While commercial shipping traffic has declined over the past few decades, Buffalo remains the second-largest city in New York State and continues to see a large amount of tourism, recreational boating, and recreational fishing. Both the Buffalo and Niagara rivers were named AOCs as part of the Great Lakes Water Quality Agreement of 1987. The upper Niagara River is defined as the portion of river above Niagara Falls. The Erie Canal, a known vector for invasive species, connects to the Great Lakes in the upper Niagara River, increasing this area's vulnerability to invasion. The aquatic habitat varies considerably within the survey area. The harbor consists of dredged channels with soft substrate, often with large expanses of submerged vegetation. Submerged riprap and/or sheet pilings dominate the shoreline within the harbor. The upper Niagara River consists of clear water with considerable flow in most locations and the substrate is dominated by a combination of clay and cobble, with submerged vegetation. The open lake area outside of the harbor and south to the westernmost shoreline boundary consists of mainly clear water with medium to large cobble/hard substrate interspersed with *Dreissena* spp. colonies. The study area was located within US waters in the easternmost part of Lake Erie at Buffalo and encompassed the Small Boat Harbor, south along approximately 16 km of shoreline, north to the Canadian border, as well as all New York waters of the upper Niagara River to Buckhorn Island. The total surface area of the survey location was approximately 21,560 ha.

METHODS

Multiple life stages of fish and macroinvertebrates were targeted for early detection in Lake Erie (USFWS 2014a). Juvenile and adult fish were sampled in each study area in an attempt to collect as many species present in the fish community as possible. Ichthyoplankton (larval fish) sampling was conducted at select study areas, mainly targeting areas with large amounts of shipping ballast water release or areas where reproduction of high risk species may occur. In addition to fish sampling, pilot benthos sampling was conducted in select study areas to determine feasibility of sampling for select non-native benthic macroinvertebrates and amphipods.

Adult/Juvenile Fish Sampling

Adult and juvenile fish were targeted using diverse sampling gears deployed at a range of water depths in an attempt to collect as many species present in the fish community as possible. Results from the different gear types were used to determine which gears collected a greater number of unique species.

Sampling gears used to target adult and juvenile fish included paired fyke nets, boat electrofishing, benthic trawling, and minnow traps. Paired fyke nets consisted of two 0.91 m x 1.22 m fyke nets constructed of 4.69 mm (3/16" delta) stretch mesh netting that were attached together with a 15 m x 0.91 m lead resulting in a paired net. Each individual net consisted of two rectangular frames 0.91 m x 1.22 m, followed by four circular rings 0.91 m in diameter. Paired fyke nets were set parallel to the shoreline or in "weed pockets" in water depths of 1.0-4.4 m. Nets were set during the day, remaining in the water overnight for a period of 12-30 hours. Effort was measured in hours fished.

Boat electrofishing was conducted during both day and night hours, in water depths of 1-3 m. A pulsed DC current 60 Hz electrical unit was used with sufficient power to induce taxis in fish. The electrofishing power was dependent upon water conductivity and the level of boat-hull oxidation. Smith Root and Midwest Lake Electrofishing System control boxes were used to generate electrical impulses used during electrofishing. Electrofishing was conducted along one 600 s transect near each predetermined randomly selected waypoint. Effort was converted to hours fished.

Benthic trawling was conducted using a Marinovich design trawl with a 4.9 m head rope, 3.8 cm stretch mesh body, and a 3.125 mm stretch mesh cod end. Trawls were recovered using a hydraulic winch or by hand. Trawl tows were performed along contours for five minutes at a speed of approximately 4 km/h, and at depths greater than 2 m. Effort was converted to hours fished. Benthic trawling was conducted only at locations where the substrate was even and composed of combinations of soft material such as sand, silt, or vegetation. Trawling was not

conducted in areas with rocky or uneven substrate, or at locations with underwater obstructions. Trawling was not conducted in the Detroit River due to factors listed above.

Minnow trap arrays consisted of Gee's minnow traps. Gee's minnow traps were constructed of 0.6 mm galvanized steel mesh with a conical design (42 mm x 23 mm). Each minnow trap end had a 25.4 mm funnel shaped trap entrance. Minnow traps were baited with bait bags containing cubed cheese (3 pieces), dry dog food (5 pieces), and night crawler (one chopped), all in each trap. Traps were set on the bottom in an array of five traps per line. Traps were set overnight for a period of 12-25 hours, and effort was measured in hours fished.

ArcGIS 10.2 was used to select sampling sites across water depth strata (<2 m, 1-2 m, and > 2 m) present in each study area according to a stratified randomized design (Hoffman et al. 2011). Study areas were predefined using polygon shapefiles in ArcGIS. A bathymetry data layer was used to define depth strata within the polygon. Random points, corresponding to GIS coordinates, were selected within each depth strata using the *Create Random Points* function in ArcGIS 10.2. Due to lack of available bathymetric data for many of the areas to be sampled (shallow, nearshore, outside of dredged areas), shape files were modified for estimated depth ranges corresponding to gear types.

Gears used during this study and the amount of effort deployed was based on recommendations from Trebitz et al. (2009) and USFWS (2014b). When a randomly selected point was unable to be sampled (e.g. wrong depth, inaccessibility), an alternate site was selected from a list of previously allocated randomized alternate locations.

All fish collected during sampling were identified to species level. When a fish could not be identified in the field, it was either preserved in 95% ethanol or frozen and brought back for identification in the lab. Tissue samples were taken on select fish whose identification was questionable, usually in addition to preserving the whole specimen for lab identification. Tissue samples were taken by clipping a small portion of a fin and either preserving it in an individual 2 mL vial with 95% ethanol or placing it in a scale envelope and dried. Tissue sample results are pending genetic barcoding analysis. All species of fish were released unharmed except Round Goby *Neogobius melanostomus* and Tubenose Goby *Proterorhinus semilunaris.* Gobies were euthanized in accordance with state regulations and the terms of scientific collection permits. Water quality data was collected at each site and included surface temperature (°C), secchi depth (m), dissolved oxygen (mg/l), and conductivity (µS/cm; at electrofishing sites).

Ichthyoplankton Sampling

Sampling gears used to target ichthyoplankton included bongo nets and light traps. Bongo nets consisted of paired conical nets (0.6 m diameter, 500 micron mesh), each fitted with a sample bucket attached to the net bottom. Bongo net tows were performed at night in waters greater than

1 m in depth, and at least one hour past sunset. Tows were five minutes in duration and with the net frame just below the surface of the water. Sampling was conducted adjacent (e.g. port or starboard side) to the sampling vessel to avoid prop wash. Upon lift the net contents were washed down into net sample buckets, then transferred to 500 ml plastic sample bottles and preserved with 95% ethanol. Quatrefoil style light traps (0.3 m diameter, 0.25 m long, gap width 5 mm, 500 micron mesh) were anchored in waters less than 1 m in depth, and fished at night from one hour past sunset for six to eight hours. Traps were recovered and the contents were washed down into a mesh bag at the bottom of the trap, then transferred to 500 ml plastic sample bottles and preserved with 95% ethanol.

All samples were preserved in 95% ethanol and brought back for identification in the lab. In the laboratory, ichthyoplankton collected in the gears were removed from other biological material and detritus in the samples and identified to the lowest taxonomic level following Auer (1982). In some cases, specimens could only be deduced to family, genus, or unidentifiable, and were reported as such. All samples were screened for Asian Carp species including Bighead, Silver, Black, and Grass Carp, and samples collected in Buffalo/upper Niagara River were also screened for Ruffe *Gymnocephalus cernuus* (Simon and Vondruska 1991; Urho 1996; Chapman 2006). Samples collected from Sandusky Bay and Maumee Bay were taxonomically identified by the U. S. Geological Survey Great Lakes Science Center, Ann Arbor, Michigan. For bongo net samples, fish from only one side of the net were identified (e.g. port or starboard), while samples from the other side were retained as a reference. In addition to morphological identification, a portion of the ichthyoplankton collected will be genetically identified, via genetic barcoding analysis, by the USFWS Fish Health Center in Lamar, Pennsylvania or U. S. Environmental Protection Agency (USEPA) National Exposure Research Laboratory in Cincinnati, Ohio. Water quality data was collected at each site and included surface temperature (°C) and dissolved oxygen (mg/l).

Site selection was performed using the same protocol as described above for juvenile/adult fish sampling.

Benthic Macroinvertebrate Sampling

Hester-Dendy colonization samplers, amphipod traps, and benthic sled were used to sample benthic invertebrates in Maumee Bay and Buffalo/upper Niagara River. Hester-Dendy colonization samplers consisted of 14 masonite plates secured and spaced on a rod. Hester-Dendy samplers were anchored in protected areas with the following criteria: locations that were not highly visible to deter vandalism, out of navigational channels, and where the samplers would remain submerged during the duration of deployment. They were left in place for 1.5 to 2 months before recovery. Once samplers were recovered, the samplers were disassembled in the field and each plate was scraped into 500 ml plastic sample bottles and preserved in 95%

ethanol. Amphipod traps were modeled after the Hensler-Hutton-Stadig (HHS) trap described by Stadig (2016). The trap consisted of a Gee's minnow trap (see description above) covered with 243 µm Nitex mesh and fitted with 17 mm rubber gaskets sewn into either end to provide openings into the trap. Amphipod traps were anchored in waters less than 1 m in depth, and fished at night from one hour past sunset for six to eight hours. Traps were recovered and the contents were washed down and concentrated into a 500 ml plastic sample bottle and preserved with 95% ethanol.

Design for the benthic sled came from Blomqvist and Lundgren (1996). Sled dimensions are 1125 mm total length, 700 mm total breadth, 400 mm cutting breadth, 55 liter bag volume. The sled was deployed from the boat while in neutral. A 2-minute tow at a speed of 3-4 km/h started once the sled settled on the bottom. The resulting sample was deposited into a wash-down bin. In the wash-down bin, the sample was agitated and cleaned, then poured through a bucket-sieve to remove mud and other detritus. Samples were preserved in 95% ethanol.

All benthos and amphipod samples were brought back for identification in the lab. Invertebrates were removed from the samples and identified to the lowest possible taxonomic level. In some cases, specimens could only be deduced to family, genus, or unidentifiable, and were reported as such. Samples collected from Maumee Bay were taxonomically identified by Badger Technical Services, Duluth, Minnesota.

Data Analysis

Catch per unit effort was determined for all fish species captured in 2016. Species accumulation theory was used to estimate juvenile and adult species richness, species accumulation, and sampling efficiency (estimated efficiency at which species are detected) for individual and combined gear types at each sampling region for 2013-2016, all years sampling occurred. Any unique or new species collected in 2016, but not seen in previous years, were noted. Also noted were singletons, a species that was captured at that location on a single occasion over the sampling series (2013-2016), and doubletons, a species that was captured at that location on two occasions over the sampling series (2013-2016). Singletons and doubletons identify rare species and contribute to rarefaction analysis as they can affect the number of predicted species (if there are many singletons and/or doubletons the amount of species predicted will increase). Sample-based rarefaction and extrapolation were conducted and species accumulation curves were calculated using the Chao asymptotic richness estimator in EstimateS (Colwell 2013, version 9.1.0) software and species abundance data (randomized pooling of data) from 2013-2016 for 10,000 sample extrapolations. The methods used followed Chao et al. (2009). Estimated species richness is the asymptote of the extrapolated rarefaction curve. The effort required to detect 95% of species present was calculated by multiplying the estimated number of species by 0.95. The resulting number of species corresponded to a number of samples (i.e., effort required for 95% detection) on the rarefaction curve by which we determined how many samples are needed to

detect 95% of the species. Sampling efficiency was calculated as the observed species richness (actual number of species collected) divided by the estimated species richness (asymptote of the rarefaction curve).

RESULTS

Adult/Juvenile Fish Sampling

Early detection and monitoring efforts for adult/juvenile fish were conducted from June 15, 2016 to October 26, 2016. Surveillance crews collected a total of 2,928 fish comprised of 43 species in the Detroit River; a total of 6,830 fish comprised of 37 species in Maumee Bay; a total of 4,116 fish comprised of 32 species in Sandusky Bay; and a total of 4,557 total fish comprised of 44 species in Buffalo/upper Niagara River. Results for each sampling location follow.

Detroit River—A total of 2,928 fish from 43 species were collected during July, August, September, and October 2016 (Table 1, Figure 2). No undocumented non-native species were identified; however, a number of existing invasive and non-native species were collected including Bigmouth Buffalo *Ictiobus cyprinellus*, Common Carp *Cyprinus carpio*, Goldfish *Carassius auratus*, Round Goby, Tubenose Goby, and White Perch *Morone americana*. The most abundant species collected from the Detroit River in 2016 were Bluegill *Lepomis macrochirus* (28.7% of total catch), Round Goby (13.0% of total catch), Brook Silverside *Labidesthes sicculus* (8.8% of total catch), Logperch *Percina caprodes* (8.4% of total catch), Spottail Shiner *Notropis hudsonius* (8.0% of total catch), Rock Bass *Ambloplites rupestris* (7.8% of total catch), and Smallmouth Bass *Micropterus dolomieu* (6.8% of total catch). Four unique species were detected in 2016 and included Black Redhorse *Moxostoma duquesnei*, Northern Hog Sucker *Hypentelium nigricans*, Rainbow Trout *Oncorhynchus mykiss*, and River Chub *Nocomis micropogon*. From 2013-2016 there have been six singletons (Northern Longear Sunfish *Lepomis megalotis*, Rainbow Trout, River Chub, Shorthead Redhorse *Moxostoma macrolepidotum*, Striped Shiner *Luxilus chrysocephalus*, and White Crappie *Pomoxis annularis*) and six doubletons (Bigmouth Buffalo, Black Redhorse, Ghost Shiner *Notropis buchanani*, Longnose Gar *Lepisosteus osseus*, Northern Hogsucker, and Spotted Gar *Lepisosteus oculatus*) collected.

A total of 573 fish representing 35 species were collected as a result of 15 nighttime electrofishing transects (2.5 hours of effort) sampled between August 23 and October 11, 2016 at bottom water temperatures between 16.2 and 25.0℃ (Table 1). The most abundant species were Brook Silverside (45.2% of total catch), Gizzard Shad *Dorosoma cepedianum* (14.4% of total catch), and Yellow Perch *Perca flavescens* (8.3% of total catch). Electrofishing collected 17 species that were unique to this gear type including Bigmouth Buffalo, Black Crappie *Pomoxis nigromaculatus*, Black Redhorse, Bowfin *Amia calva*, Brook Silverside, Emerald Shiner *Notropis atherinoides*, Freshwater Drum *Aplodinotus grunniens*, Gizzard Shad, Golden Redhorse *Moxostoma erythrurum*, Golden Shiner *Notemigonus crysoleucas*, Goldfish, Longnose Gar,

Northern Hog Sucker, Northern Pike *Esox Lucius,* Rainbow Trout, River Chub, and Silver Redhorse *Moxostoma anisurum*.

A total of 2,051 fish representing 24 species were collected as a result of 15 paired fyke net sets (339.1 hours of effort) sampled overnight between July 25 and August 18, 2016 at bottom water temperatures between 24.9 and 26.3℃ (Table 1). The most abundant species were Bluegill (40.1% of total catch), Logperch (11.3% of total catch), and Spottail Shiner (11.2% of total catch). Fyke nets captured seven species unique to this gear including Black Bullhead *Ameiurus melas*, Creek Chub *Semotilus atromaculatus*, Muskellunge *Esox masquinongy*, Sand Shiner *Notropis stramineus*, Tubenose Goby, White Perch, and Yellow Bullhead *Ameiurus natalis*.

A total of 304 fish representing nine species were collected as a result of 15 minnow trap arrays (322.6 hours of effort) fished overnight between August 9 and August 11, 2016 at bottom water temperatures between 24.7 and 26.9℃ (Table 1). The most abundant species captured were Round Goby (67.7% of total catch), Rock Bass (10.9% of total catch), and Yellow Perch (10.2% of total catch). Minnow traps collected one species unique to this gear, Northern Madtom *Noturus stigmosus*.

Maumee Bay—A total of 6,830 fish from 37 species were collected during August, September, and October 2016 (Table 2, Figure 3). No undocumented non-native species were identified; however, a number of previously established non-native species were collected including Bigmouth Buffalo, Common Carp, Goldfish, Round Goby, and White Perch. The most abundant species captured in Maumee Bay during 2016 were White Perch (35.2% of total catch), Bluegill (19.0% of total catch), Spottail Shiner (11.6% of total catch), Mimic Shiner *Notropis volucellus* (9.4% of total catch), and Gizzard Shad (8.6% of total catch). Six unique species were detected in 2016 and included Bigmouth Buffalo, Blacknose Shiner *Notropis heterolepis*, Common Shiner *Luxilus cornutus*, Longnose Gar, Silver Chub *Macrhybopsis storeriana*, Smallmouth Bass. From 2013-2016 there have been seven singletons (Banded Killifish, Bigmouth Buffalo, Blacknose Shiner, Ghost Shiner, Greater Redhorse *Moxostoma valenciennesi*, Longnose Gar, and Silver Redhorse) and eight doubletons (Alewife, Bowfin, Common Shiner, Golden Redhorse, Golden Shiner, Northern Pike, Shorthead Redhorse, and Silver Chub) collected.

A total of 726 fish representing 22 species were collected as a result of 15 nighttime electrofishing transects (2.5 hours of total effort) sampled between September 12 and October 5, 2016 at bottom water temperatures between 18.9 and 24.9℃ (Table 2). The most abundant species were Gizzard Shad (74.6% of total catch), Brook Silverside (3.9% of total catch), and Walleye *Sander vitreus* (3.9% of total catch). Electrofishing captured five species unique to this gear type including Bigmouth Buffalo, Bluntnose Minnow *Pimephales notatus*, Goldfish, Northern Pike, and Yellow Bullhead.

A total of 3,045 fish representing 30 species were collected as a result of 15 paired fyke net sets (336.0 hours of effort) sampled overnight between August 29 and September 1, 2016 at bottom water temperatures between 24.3 and 28.0°C (Table 2). The most abundant species were Bluegill (42.0% of total catch), White Perch (26.6% of total catch), and Spottail Shiner (11.6% of total catch). Fyke nets captured 11 species unique to this gear including Black Bullhead, Blacknose Shiner, Bowfin, Common Shiner, Golden Shiner, Logperch, Longnose Gar, Quillback *Carpiodes cyprinus*, Rock Bass, White Perch, and White Sucker *Catostomus commersonii*.

A total of 3,059 fish representing 18 species were collected as a result of 15 bottom trawl tows (1.25 hours of effort) conducted on September 21 and September 22, 2016 at bottom water temperatures between 22.4 and 23.1°C (Table 2). The most abundant species were White Perch (51.3% of total catch), Mimic Shiner (20.6% of total catch), and Spottail Shiner (14.2% of total catch). Bottom trawls captured one species unique to this gear, Silver Chub.

Sandusky Bay—A total of 4,116 fish from 32 species were collected during September and October 2016 (Table 3, Figure 4). No undocumented non-native species were identified; however, a number of existing non-native species were collected including Bigmouth Buffalo, Common Carp, Goldfish, Rainbow Smelt, Round Goby, and White Perch. The most abundant species collected from Sandusky Bay in 2016 were White Perch (68.5% of total catch) and Gizzard Shad (12.5% of total catch); with Yellow Perch, Mimic Shiner, and White Crappie (3% of total catch each) to a lesser percent. Four unique species were detected in 2016 and included Brook Silverside, Golden Shiner, Orangespotted Sunfish *Lepomis humilis*, and Silver Chub. From 2013-2016 ten singletons (Alewife, Bluntnose Minnow, Fathead Minnow *Pimephales promelas*, Golden Redhorse, Golden Shiner, Longnose Gar, Orangespotted Sunfish, Rock Bass, Silver Chub, and Silver Redhorse) and one doubleton (Spotted Sucker *Minytrema melanops*) have been collected.

A total of 639 fish representing 17 species were collected as a result of 15 nighttime electrofishing transects (2.5 hours of effort) sampled on October 3 and October 4, 2016 at bottom water temperatures between 17.4 and 21.0°C (Table 3). The most abundant species were Gizzard Shad (69.9% of total catch), White Perch (12.8% of total catch), and Yellow Perch (5.6% of total catch). Electrofishing captured four species unique to this gear type including Bluntnose Minnow, Brook Silverside, Golden Shiner, and Largemouth Bass.

A total of 1,167 fish representing 22 species were collected as a result of 15 paired fyke net sets (320.9 hours of effort) sampled overnight between September 19 and September 22, 2016 at bottom water temperatures between 22.1 and 23.2°C (Table 3). The most abundant species were White Perch (67.1% of total catch), White Crappie (10.8% of total catch), and Channel Catfish *Ictalurus punctatus* (5.8% of total catch). Fyke nets collected five species unique to this gear

including Black Crappie, Brown Bullhead *Ameiurus nebulosus*, Orangespotted Sunfish, Sand Shiner, and Yellow Bullhead.

A total of 2,310 fish representing 21 species were collected as a result of 15 bottom trawl tows (1.25 hours effort) conducted on September 19 and September 20, 2016 at bottom water temperatures between 22.4 and 23.0°C (Table 3). The most abundant species were White perch (84.6% of total catch) and Mimic Shiner (5.4% of total catch). Bottom trawls collected six species unique to this gear including Bigmouth Buffalo, Rainbow Smelt, Silver Chub, Smallmouth Bass, Trout-perch *Percopsis omiscomaycus*, and hybridized White Bass/White Perch *Morone chrysops x Morone americana*.

Buffalo/upper Niagara River—A total of 4,557 fish representing 44 species were collected between June and October 2016 (Table 4, Figure 5). An expansion of the non-native distribution of Blueback Herring *Alosa aestivalis* was observed in 2016. No previously reported observations exist for this species west of Oswego, New York (USGS 2017). Six individuals were collected in the upper Niagara River and reported through appropriate channels. A number of established invasive species were collected including Alewife, Common Carp, Goldfish, Round Goby, Rudd, and White Perch. Four unique species were detected in 2016 and included Blacknose Shiner, Blueback Herring, Iowa Darter *Etheostoma exile*, and Rainbow Trout. From 2013-2016, 11 singletons (Bigmouth Shiner *Notropis dorsalis*, Blacknose Shiner, Blueback Herring, Brown Trout *Salmo trutta*, Fallfish *Semotilus corporalis*, Iowa Darter, Mimic Shiner, Rainbow Trout, Smallmouth Buffalo *Ictiobus bubalus*, Tessellated Darter *Etheostoma olmstedi*, and White Crappie) and four doubletons (Channel Catfish, Longnose Gar, Trout-Perch, and Yellow Bullhead) have been collected.

A total of 1,995 fish representing 40 species were collected using 35 day and six night electrofishing transects (7.28 hours of effort) sampled between June 15 and September 19, 2016 at surface water temperatures between 18.8 and 26.7°C (Table 4). The most abundant species encountered were White Sucker (22.3% of total catch), Bluntnose Minnow (10.3% of total catch), Yellow Perch (9.7% of total catch), and Largemouth Bass (5.9% of total catch). Electrofishing captured 13 species unique to this gear including Blueback Herring, Freshwater Drum, Golden Shiner, Greater Redhorse, Hornyhead Chub *Nocomis biguttatus*, Iowa Darter, Muskellunge, Northern Hog Sucker, Northern Pike, Quillback, Rainbow Trout, Shorthead Redhorse, and Silver Redhorse.

A total of 2,532 fish representing 31 species were collected as a result of 12 paired fyke net sets (256.18 hours of effort) sampled overnight between September 12 and September 15, 2016 at surface water temperatures between 22.1 and 24.8°C (Table 4). The most abundant species were Bluntnose Minnow (27.8% of total catch), Bluegill (18.0% of total catch), Spottail Shiner (12.7% of total catch), and Emerald Shiner (11.0% of total catch). Fyke nets collected four species

unique to this gear including Black Crappie, Blacknose Shiner, Common Shiner, and White Bass *Morone chrysops*.

A total of 30 fish representing five species were collected as a result of 10 bottom trawl tows (1.17 hours effort) conducted on September 9 and October 9, 2016 at surface water temperatures between 24.5 and 25.4°C (Table 4). The most abundant species were Yellow Perch (60.0% of total catch), Spottail Shiner (16.7% of total catch), Round Goby (10% of total catch), and Bluegill (10.0% of total catch). Bottom trawls collected no species unique to this gear.

Rarefaction and Species Accumulation

The efficiency for juvenile and adult fish sampling gears was generated for all Lake Erie sampling locations (Table 5) based on data collected from 2013 to 2016. Our sampling efficacy target of 95% detection was obtained for the Detroit River (96.4% efficiency) and is very close to being obtained in Maumee Bay (94.0% efficacy). The highest combined gear sampling efficiency was observed at the Detroit River (96% of species detected), followed by Maumee Bay (94% of species detected), and Buffalo/upper Niagara River (80% of species detected). The lowest combined gear sampling efficacy was at Sandusky Bay (45% of species detected). Fyke netting was most effective at species detection at most locations except the Detroit River where minnow trapping was most effective. Bottom trawling was least effective at species detection at most locations except Sandusky Bay where electrofishing was least effective. Based on rarefaction estimates, the number of samples needed to detect 95% of species present was lowest for the Detroit River (115-116) and highest for Sandusky Bay (1,972-1,973). Species accumulation curves were generated for all Lake Erie sampling locations with gears combined (Figures 6-9) and for each location by gear type (Figures 10-13). Results by sampling location follow.

Detroit River—The goal of 95% detection of estimated species present was met at the Detroit River. Sampling efficiency was 95.0% (Table 5). A total of 60 species are estimated to be present as a result of 2013-2016 data analysis; while 56 species were captured using all gears (Figure 6). To reach the 95% detection threshold of species present, 55 species needed to be captured (Table 5). Minnow traps collected 14 species and had the highest sampling efficacy at 86.4% (Figure 10). Electrofishing collected 46 species and had the lowest sampling efficiency at 79.5%. Fyke nets captured 46 species and had a sampling efficacy of 82.2%.

Maumee Bay—The goal of 95% detection of estimated species present was nearly attained at the Maumee Bay location. Sampling efficiency was 94.0% (Table 5). A total of 51 species are estimated to be present as a result of 2013-2016 data analysis; while 48 species were captured using all gears (Figure 7). To reach the 95% detection threshold of species present, 48 species needed to be captured (Table 5). A total of 154-155 samples will be required to reach this goal. Fyke nets collected 45 species and had the highest sampling efficacy at 90.0%, and bottom

trawls collected 23 species and had the lowest sampling efficiency at 79.6%. Electrofishing was only conducted during 2014 and 2016 and collected 23 species with an 87.0% sampling efficacy (Figure 11).

Sandusky Bay—Sampling efficiency was 45.2% in Sandusky Bay as a result of 2013-2016 data analysis (Table 5). An estimated 91 species are present according to the data analysis; while 41 species were captured using all gears (Figure 8). To reach 95% detection of all species present in Sandusky Bay, we need to capture 86 species (Table 5). A total of 1,972-1,973 samples will be required to reach this goal. Fyke nets collected 27 species and had the highest sampling efficiency at 68.8%, while electrofishing captured 28 species and had the lowest sampling efficiency at 48.6% (Figure 12). Electrofishing was not conducted in 2015. Bottom trawls collected 27 species and had a sampling efficiency of 60.4%.

Buffalo/upper Niagara River—Sampling efficiency was 80.5% in Buffalo/upper Niagara River as a result of 2013-2016 data analysis (Table 5). An estimated 77 species are present as according to the data analysis; while 62 species were captured using all gears (Figure 9). To reach 95% detection of all species present (73 species), 616-617 samples will be required from Buffalo and the Niagara River (Table 5). Paired fyke nets had the highest sampling efficiency at 88.7%, while bottom trawling had the lowest at 37.9% sampling efficiency. Electrofishing had an 81.9% sampling efficiency (Figure 13).

Ichthyoplankton Sampling

Early detection and monitoring efforts for ichthyoplankton were conducted from May 23, 2016 to October 26, 2016. Samples were identified to the lowest possible taxonomic level, either genus or species. Surveillance crews collected a total of 6,894 fish that represented 11 species and an additional eight genus groupings in Maumee Bay; a total of 2,326 fish that represented nine species and an additional seven genus groupings in Sandusky Bay; and a total of 219 fish that represented 15 species and one genus grouping in Buffalo/upper Niagara River. No Asian Carp species or Ruffe were identified. Results for each sampling location follow.

Maumee Bay—A total of 6,894 ichthyoplankton from 11 species and eight genus groupings were collected during May and July 2016 at surface water temperatures between 17.4 and 22.8℃ and 25.3 to 27.2℃, respectively (Table 6, Figure 14). No new non-native species were identified; however previously established invasive species were collected including Common Carp, White Perch, and Gobiidae species. The most abundant ichthyoplankton species captured in Maumee Bay during 2016 were White Bass/White Perch at 4,789 individuals and 69.5% of the total catch.

Bongo nets were used to collect a total of 6,828 fish representing 10 species and seven genus groupings in Maumee Bay over 22 nighttime net tows (1,540.1 m^3 of effort). Sampling was conducted May 23-26 and July 6-19, 2016. The most abundant species collected with bongo nets

was White Bass/White Perch at 70.0% of the bongo net catch. Light traps were used to collect a total of 66 fish representing seven species and six genus groupings at Maumee Bay over eight nighttime trap sets (26.53 hours of effort). Sampling was conducted May 25-26 and July 7-20, 2016. The most abundant species collected with light traps were from the *Pomoxis* species grouping at 21.2% of the light trap catch.

Sandusky Bay—A total of 2,326 ichthyoplankton from nine species and seven genus groupings were collected during June and July 2016 at surface water temperatures between 24.5 and 27.4°C (Table 7, Figure 15). No new non-native species were identified; however, a number of previously established invasive species were collected including Common Carp, Goldfish, Rainbow Smelt, White Perch, and Gobiidae species. The most abundant larval fish species captured in Sandusky Bay during 2016 were Gizzard Shad at 1,147 individuals and 49.3% of the total catch.

Bongo nets were used to collect a total of 2,175 fish representing seven species and seven genus groupings in Sandusky Bay over 24 nighttime net tows (2,013.0 m^3 of effort). Sampling was conducted June 27-30 and July 11-12, 2016. The most abundant species collected with bongo nets was Gizzard Shad at 52.7% of the bongo net catch. Light traps were used to collect a total of 151 fish representing four species and four genus groupings in Sandusky Bay over six nighttime trap sets (26.23 hours of effort). Sampling was conducted June 29 and July 12, 2016. The most abundant species collected with light traps were from the *Lepomis* species grouping at 54.9% of the light trap catch.

Buffalo/upper Niagara River—A total of 219 ichthyoplankton representing 15 species and one genus grouping were collected during June and July 2016 at surface temperatures between 20.6 and 26.7°C (Table 8, Figure 16). No new non-native species were identified; however, a number of existing invasive species were collected including Alewife, Round Goby, and White Perch. The most abundant larval fish species captured in Buffalo during 2016 was Round Goby (59% of total catch).

Bongo nets were used to collect a total of 136 fish representing 11 species and one genus grouping at Buffalo over 19 nighttime net tows (1,443.02 m^3 of effort). Sampling was conducted on June 23-24, June 27-28, and July 11-13, 2016. The most abundant species were Round Goby (61% of total catch), White Perch (15% of total catch), and Emerald Shiner (6% of total catch). Light traps were used to collect a total of 83 fish representing six species at Buffalo over 10 nighttime trap sets (54.15 hours of effort). Sampling was conducted on June 23 and 27, and July 12, 2016. The most abundant species were Round Goby (55% of total catch), Bluegill (24% of total catch), and Pumpkinseed *Lepomis gibbosus* (10% of total catch). Due to continuously low yearly catches (2014: 189, 2015: 108, 2016: 219) of larval fish within this sampling area, a pilot

study was conducted comparing different ichthyoplankton collection gears to inform future sampling efforts (see Appendix B).

Benthic Macroinvertebrate Sampling

Maumee Bay—Benthos and amphipod samples were collected from May to October 2016 (Figure 17). Hester-Dendy colonization samplers (5 samplers) were set from August 19 to October 11, 2016. Amphipod traps (21 lifts) were sampled May 24-26 and July 7-20, 2016. Results for Maumee Bay are pending and expected in April 2017.

Buffalo/upper Niagara River—Benthos and amphipod samples were collected using a benthic sled (16 tows) from August 2 to October 4, 2016 (Table 9, Figure 18). Sampling collected 4,065 organisms that included a total of 3,402 benthic macroinvertebrates from at least 11 species and 663 amphipods from 2 species. No new non-native species were identified; however, several existing invasive species were collected including *Echinogammarus ischnus.* The most abundant organisms collected in Buffalo/upper Niagara River during 2016 were 3,104 gastropods from the Hydrobiidae family which includes Hydrobiidae sp. *Amnicola limosa*, *Cincinnatia cincinnatiensis*, *Marstonia decepta*, *Probythinella lacustris*, *Somatogyrus subglobosus* (76.3% of total sample).

DISCUSSION

The 2016 field season was the fourth year of sampling for the early detection of non-native species at Lake Erie locations using a vector based risk analysis (USFWS 2014a). A large number of juvenile and adult fish species (both native and non-native) were collected with an assortment of gears during 2013-2016. One previously undocumented non-native species was captured. Blueback Herring were collected at the upper Niagara River in 2016. The sighting was a westward expansion of its non-native range from previous observations at Oswego, the Oswego River, and Oneida Lake in 1994 and 1995 (USGS 2017).

Targeting juvenile and adult fish can be challenging due to fish behavior, refined habitat requirements, and gear avoidance. Non-native species at low abundances can be difficult to detect as juveniles or adults using traditional sampling gear. To account for this, multiple gear types were used to target juveniles and adults. Aside from Sandusky Bay (45.2% of species detected), greater than 80% of species were estimated to be detected at all sampling locations and greater than 95% of species were estimated to be detected in the Detroit River. Sandusky Bay was likely estimated at a much lower percentage of species detected due to the number of species rarely caught. For example, 16 of the 41 species captured were only caught in five or fewer samples and 10 were only captured in one sample (153 total samples). However, the detection efficiency was still below the designated 95% threshold required to detect rare species (non-native species at first introduction; Hoffman et al. 2011) for Maumee Bay, Sandusky Bay, and Buffalo/upper Niagara River. Rarefaction analysis indicated considerable additional sampling

effort is required to detect species at low abundances using the current sampling regime in Sandusky Bay and Buffalo/upper Niagara River.

Paired fyke nets generally had the highest efficiency among gear types (beside minnow traps in the Detroit River), and were more effective at catching greater numbers of individuals. However, electrofishing generally captured more unique species than the other gear types (beside paired fyke nets in Maumee Bay). The larger sample size for paired fyke nets (compared to electrofishing) may have played a role the higher efficiency. Despite high overall performance of paired fyke nets, it is recognized that a single sampling gear approach only provides a partial representation of the juvenile and adult fish assemblage (Murphy and Willis 1996), and multi-gear approaches are required to adequately characterize fish communities (Jackson and Harvey 1997; Eggleton et al. 2010; Hoffman et al. 2011; Ruetz et al. 2007).

Non-native species may be introduced via a variety of pathways at all life stages including release as unwanted pets, mixed with live bait, and transport in ballast water. Therefore, it is critical for early detection monitoring of non-native species to target all life stages to provide the best chance at detecting a new non-native species at low population levels because eradication and control efforts are most effective when implemented early (Hulme 2006). Pritt et al. (2015) suggested that larval fish have a greater detection probability than that of adults due to their inherent abundance and ease of capture, thus making them a valuable tool for detecting newly establishing invasive species. Unfortunately, traditional taxonomic identification of ichthyoplankton is difficult. DNA identification using genetic barcoding is a relatively new and promising method for larval fish identification but current limitations, such as genetically similar conspecifics and incomplete species genomic barcoding libraries, hinder its sole use (Loh et al. 2014, Serrao et al. 2014). However, the coupling of traditional and DNA barcoding identification can result in a more robust assessment of species-level identification of ichthyoplankton (Overdyk et al. 2016). Overall, 2016 ichthyoplankton sampling in Lake Erie resulted in a total of 9,439 specimens identified to the lowest taxonomic level representing 23 species, five genus groupings, and three family level groupings with no new invasive species detected. A portion of the ichthyoplankton samples collected will be identified via DNA genetic barcoding to further verify the results of the traditional taxonomic identification reported here.

Pilot studies sampling benthic macroinvertebrates, while limited at this time, are important and macroinvertebrate sampling may be expanded to other locations in the future. Incorporating benthic sampling into early detection for non-native species makes the program more comprehensive, targeting high risk benthos and amphipods including the golden mussel *Limnoperna fortunei* and the killer shrimp *Dikerogammarus villosus*. Both the golden mussel and killer shrimp have become problematic in areas where they have become established and invasive (Darrigan and Pastorino 2003; van Riel et al. 2006).

Ultimately, designing a long-term monitoring program is challenging due to the need to balance detection efficiency with available resources (Trebitz et al. 2009). These challenges become exacerbated when considering early detection monitoring for newly introduced non-native species because of the exorbitant amounts of effort and high survey efficiency (≥95% species detection) required. It is therefore beneficial to use results from previous sampling as a guide to adapt future survey design and improve overall sampling efficiency and effectiveness. For example, in Duluth-Superior Harbor, Lake Superior, Hoffman et al. (2011) used a re-sampling approach and found that using a targeted sampling design (i.e. resampled areas with high species richness) resulted in greater species richness and detected non-native species with a significantly higher probability than a spatially balanced random design (also see Trebitz et al. 2009). Although the effort required to detect rare (i.e. non-natives at first introduction) species remained large, non-metric multi-dimensional scaling analysis could also be used to determine whether gear types are capturing complementary or redundant species assemblage data (cf. Ruetz et al. 2007; Frances et al. 2014). For example, if two gear types capture redundant assemblages then the least efficient gear (according to the ability to catch unique species) could be eliminated, focusing additional effort towards the most efficient gear types, and thereby increase survey effort and theoretically sampling efficiency.

In closing, the early detection and monitoring program for non-native species will continue in Lake Erie during 2017. Survey design will continue to be critically re-evaluated following the 2017 field season. All available options for increasing sampling efficiency to provide the most comprehensive early detection and monitoring program for non-native species will be considered.

REFERENCES

Aron, W. I., and S. H. Smith. 1971. Ship canals and aquatic ecosystems. Science 174:13-20.

ACRCC (Asian Carp Regional Coordinating Committee). 2016. Fiscal Year 2017 Asian carp control strategy framework. Available: http://www.asiancarp.us/documents/2017ActionPlan.pdf. (February 2017).

ASA (American Sportfishing Association). 2008. Today's angler: a statistical profile of anglers, their targeted species, and expenditures. American Sportfishing Association, Alexandria, Virginia.

Auer, N. A., editor. 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Special Publication 82-3. Great Lakes Fishery Commission, Ann Arbor, Michigan.

Baerwaldt, K., A. Benson, and K. Irons. 2013. Asian Carp distribution in North America. Report to the Asian Carp Regional Coordinating Committee, April 2013.

Blomqvist, S., and L. Lundgren. 1996. A benthic sled for sampling soft bottoms. Helgoläner Meeresunters 50:453-456.

Chao, A., R. K. Colwell, C. W. Lin, and N. J. Gotelli. 2009. Sufficient sampling for asymptotic minimum species richness estimators. Ecology 90(4):1125-1133.

Chapman , D. C. 2006. Early development of four cyprinids native to the Yangtze River, China. U. S. Geological Survey Data Series 239, pp. 51.

Chapman, D. C., J. J. Davis, J. A. Jenkins, P. M. Kocovsky, J. G. Miner, J. Farver, and P. R. Jackson. 2013. First evidence of Grass Carp recruitment in the Great Lakes Basin. Journal of Great Lakes Research 39:547-554.

Chick, J. H., and M. A. Pegg. 2001. Invasive carp in the Mississippi River Basin. Science 292:2250-2251.

Colwell, R. K. 2013. EstimateS: statistical estimation of species richness and shared species from samples. Version 9. Available: http://purl.oclc.org/estimates. (December 2016).

Darrigan, G., and G. Pastorino. 2003. The golden mussel, *Limnoperna fortunei* (Dunker, 1857) (Bivalvia, Mytilidae), in the neotropical region: a 10 year story of invasion. Tentacle 11:8-9.

Dissanayake, A. A., C. M. Wagner, and M. G. Nair. 2016. Chemical characterization of lipophilic constituents in the skin of migratory adult sea lamprey from the Great Lakes region. PLoS one 11(12):e0168609.

Eggleton, M. A., J. R Jackson, and B. J. Lubinski. 2010. Comparison of gears for sampling littoral-zone fishes in floodplain lakes of the Lower White River, Arkansas. North American Journal of Fisheries Management 30(4):928-939.

Embke, H. S., P. M. Kocovsky, C. A. Richter, J. J. Pritt, C. M. Mayer, and S. S. Qian. 2016. First direct confirmation of grass carp spawning in a Great Lakes tributary. Journal of Great Lakes Research 42(4):899-903.

Evans, D. O., and D. H. Loftus. 1987. Colonization of inland lakes in the Great Lakes region by Rainbow Smelt, *Osmerus mordax*: their freshwater niche and effects on indigenous fishes. Canadian Journal of Fisheries and Aquatic Sciences 44:249-266.

Fisher, J. P., J. D. Fitzsimmons, G. F. Combs, and J. M. Spitsbergen. 1996. Naturally occurring thiamine deficiency causing reproductive failure in Finger Lakes Atlantic Salmon and Great Lakes Lake Trout. Transactions of the American Fisheries Society 125:167-178.

Frances, J. T., J. A. Chiotti, J. C. Boase, M. V. Thomas, B. A. Manny, and E. F. Roseman. 2014. A description of the nearshore fish communities in the Huron-Erie Corridor using multiple gear types. Journal of Great Lakes Research 40:52-61.

GLMRIS (Great Lakes Mississippi River Interbasin Study). 2011. Non-native species of concern and dispersal risk for the Great Lakes and Mississippi River Interbasin Study.

GLRI (Great Lakes Restoration Initiative). 2014. Great Lakes Restoration Initiative Action Plan II. Available: https://www.glri.us//actionplan/pdfs/glri-action-plan-2.pdf. (March 2016).

Great Lakes Water Quality Agreement. 1987. Protocol amending the agreement between Canada and The United States of America on Great Lakes water quality, 1978, as amended on October 16, 1983 and on November 18, 1987 and on September 7, 2012.

Hoffman, J. C., J. R. Kelly, A. S. Trebitz, G. S. Peterson, and C. W. West. 2011. Effort and potential efficiencies for aquatic non-native species early detection. Canadian Journal of Fisheries and Aquatic Sciences 68:2064-2079.

Hoffman, J. C., J. Schloesser, A. S. Trebitz, G. S. Peterson, M. Gutsch, H. Quinlan, and J. R. Kelly. 2016. Sampling design for early detection of aquatic invasive species in Great Lakes ports. Fisheries 41(1):26-37.

Hulme, P. E. 2006. Beyond control: wider implications for the management of biological invasions. Journal of Applied Ecology 43:835-847.

Jackson, D. A., and H. H. Harvey. 1997. Qualitative and quantitative sampling of lake fish communities. Canadian Journal of Fisheries and Aquatic Sciences 54:2807-2813.

Jones, M. L. 2007. Toward improved assessment of Sea Lamprey population dynamics in support of cost-effective Sea Lamprey management. International Association of Great Lakes Research 33:35-47.

Kolar, C. S., and D. M. Lodge. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science 298:1233-1236.

Laws, E. A., and R. S. J. Weisburd. 1990. Use of Silver Carp to control algal biomass in aquaculture ponds. Progressive Fish-Culturist 52:1-8.

Leung, B., D. Lodge, D. Finnoff, J. Shogren, M. Lewis, and G. Lamberti. 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proceedings of the Royal Society of London B 269:2407-2413.

Loh, W. K. W., P. Bond, K. J. Ashton, D. T. Roberts, and I. R. Tibbetts. 2014. DNA barcoding of freshwater fishes and the development of a quantitative qPCR assay for the species-specific detection and quantification of fish larvae from plankton samples. Journal of Fish Biology 85(2):307-328.

Lovell, S. J., S. F. Stone, and L. Fernandez. 2006. The economic impact of aquatic invasive species: a review of the literature. Agricultural and Resource Economics Review 35:195-208.

MICRA (Mississippi Interstate Cooperative Resource Association). 2002. Asian carp threat to the Great Lakes. River Crossings: the Newsletter of the Mississippi Interstate Cooperative Resource Association 11(3):1-2.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. International Association of Great Lakes Research 19:1-54.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1994. Exotic species and the integrity of the Great Lakes: lessons from the past. Bioscience 44:666-676.

Morrison, B. J., J. C. Casselman, T. B. Johnson, and D. L. Noakes. 2004. New Asian Carp genus (*Hypophthalmichthys*) in Lake Erie. Fisheries 29:6, 7, 44.

Murphy, B. R., and D. W. Willis, editors. 1996. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

NOAA (National Oceanic and Atmospheric Administration). 2016. Great Lakes Aquatic Nonindigenous Species Information System. Available: http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html. (March 2016).

Overdyk, L. M., E. Holm, S. S. Crawford, and R. H. Hanner. 2016. Increased taxonomic resolution of Laurentian Great Lakes ichthyoplankton through DNA barcoding: a case study comparison against visual identification of larval fishes from Stokes Bay, Lake Huron. Journal of Great Lakes Research 42(4):812-818.

Pritt, J. J., E. F. Roseman, J. E. Ross, and R. L. DeBruyne. 2015. Using larval fish community structure to guide long-term monitoring of fish spawning activity. North American Journal of Fisheries Management 35(2):241-252.

Ricciardi, A. 2006. Patterns of invasion in the Laurentian Great Lakes in relation to changes in vector activity. Diversity and Distributions 12:425-433.

Rosaen, A. L., E. A. Grover, and C. W. Spencer. 2012. The cost of aquatic invasive species to Great Lakes states. Anderson Economic Group, East Lansing, Michigan.

Rothlisberger, J. D., D. C. Finnoff, R. M. Cooke, and D. M. Lodge. 2012. Ship-borne nonindigenous species diminish Great Lakes ecosystem services. Ecosystems 15(3):1-15.

Ruetz, C. R. III, D. G. Uzarski, D. M. Kreuger, and E. S. Rutherford. 2007. Sampling a littoral fish assemblage: comparison of small-mesh fyke netting and boat electrofishing. North American Journal of Fisheries Management 2793:825-831.

Serrao, N. R., D. Steinke, and R. H. Hanner. 2014. Calibrating snakehead diversity with DNA barcodes: expanding taxonomic coverage to enable identification of potential and established invasive species. PloS one 9(6):e99546.

Simon, T. P., and Vondruska, J. T. 1991. Larval identification of the ruffe, *Gymnocephalus cernuus* (Linnaeus) (Percidae: Percini), in the St. Louis River Estuary, Lake Superior drainage basin, Minnesota. Canadian Journal of Zoology 69(2):436-442.

Smith, B. R., and J. J. Tibbles. 1980. Sea Lamprey (*Petromyzon marinus*) in Lakes Huron, Michigan, and Superior: history of invasion and control 1936-78. Canadian Journal of Fisheries and Aquatic Sciences 37:1780-1808.

Stadig, E. 2016. Evaluating trap design for capture of amphipods in western Lake Erie. Master's thesis. Indiana University-Purdue University Fort Wayne, Fort Wayne, Indiana.

Stone, N. C., E. D. Heikes, and D. Freeman. 2000. Bighead Carp. Southern Regional Aquaculture Center Publication 438. Southern Regional Aquaculture Center, Stoneville, Mississippi.

Trebitz, A. S., J. R. Kelly, J. C. Hoffman, G. S. Peterson, and C. W. West. 2009. Exploiting habitat and gear patterns for efficient detection of rare and non-native benthos and fish in Great Lakes coastal ecosystems. Aquatic Invasions 4:651-667.

Urho, L. 1996. Identification of perch (*Perca fluviatilis*), pikeperch (*Stizostedion lucioperca*) and ruffe (*Gymnocephalus cernuus*) larvae. In Annales Zoologici Fennici. Finnish Zoological and Botanical Publishing Board. pp. 659-667.

USEPA (U. S. Environmental Protection Agency). 2008. Predicting future introductions of nonindigenous species to the Great Lakes. EPA/600/R-08/066F. National Center for Environmental Assessment, Washington, DC. Available: http://www.epa.gov/ncea. (February 2017).

USFWS (U. S. Fish and Wildlife Service). 2014a. Lake Erie implementation plan for the early detection of non-native fishes and select benthic macroinvertebrates. U. S. Fish and Wildlife Service, Alpena Fish and Wildlife Conservation Office, Alpena, Michigan and Lower Great Lakes Fish and Wildlife Conservation Office, Basom, New York.

USFWS. 2014b. Recommended sampling gear types and standard operating procedures for the early detection of non-native fishes and select benthic macroinvertebrates in the Great Lakes.

USFWS. 2014c. Strategic framework for the early detection in monitoring of non-native fishes and select benthic macroinvertebrates in the Great Lakes. Great Lakes Comprehensive Aquatic Invasive Species Early Detection Monitoring Plan.

USFWS. 2016. Early detection and monitoring of non-native fishes in Lake Erie, 2013-2015. U. S. Fish and Wildlife Service, Alpena Fish and Wildlife Conservation Office, Alpena, Michigan and Lower Great Lakes Fish and Wildlife Conservation Office, Basom, New York.

USGS (U. S. Geological Survey). 2017. Nonindigenous Aquatic Species Database, Gainesville, Florida. Available: http://nas.er.usgs.gov. (January 2017).

van Riel, M. C., G. van der Velde, S. Rajagopal, S. Marguillier, F. Dehairs, and A. bij de Vaate. 2006. Trophic relationships in the Rhine food web during invasion and after establishment of the Ponto-Caspian invader *Dikerogammarus villosus*. Hydrobiologia 565:39-58.

Vanderploeg, H. A., T. F. Nalepa, D. J. Jude, E. L. Mills, K. T. Holeck, J. R. Liebig, I. A. Grigorovich, and H. Ojaveer. 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59:1209-1228.

Vörös, L., I. Oldal, M. Présing, and K. V. Balogh. 1997. Size-selective filtration and taxon specific digestion of plankton algae by Silver Carp (*Hypophthalmichthys molitrix* Val.). Hydrobiologia 342/343:223-228.

TABLES

TABLE 1. Catch summary for juvenile and adult fish species captured from the Detroit River during 2016.

		Electrofishing (Night)		Paired Fyke Net		Minnow Trap Array		
Scientific name	Common name	Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	Total
Ictiobus cyprinellus	Bigmouth Buffalo ^	1	0.400	0	0.000	0	0.000	1
Ameiurus melas	Black Bullhead	0	0.000	6	0.018	0	0.000	6
Pomoxis nigromaculatus	Black Crappie	1	0.400	0	0.000	0	0.000	1
Moxostoma duquesnei	Black Redhorse	16	6.400	0	0.000	0	0.000	16
Lepomis macrochirus	Bluegill	5	2.000	823	2.427	12	0.037	840
Pimephales notatus	Bluntnose Minnow	7	2.800	60	0.177	5	0.015	72
Amia calva	Bowfin	3	1.200	0	0.000	0	0.000	3
Labidesthes sicculus	Brook Silverside	259	103.600	0	0.000	0	0.000	259
Ameiurus nebulosus	Brown Bullhead	9	3.600	14	0.041	0	0.000	23
Cyprinus carpio	Common Carp ^	3	1.200	3	0.009	0	0.000	6
Semotilus atromaculatus	Creek Chub	0	0.000	1	0.003	0	0.000	1
Notropis atherinoides	Emerald Shiner	7	2.800	0	0.000	0	0.000	7
Aplodinotus grunniens	Freshwater Drum	3	1.200	0	0.000	0	0.000	3
Dorosoma cepedianum	Gizzard Shad	83	33.200	0	0.000	0	0.000	83
Moxostoma erythrurum	Golden Redhorse	1	0.400	0	0.000	0	0.000	1
Notemigonus crysoleucas	Golden Shiner	3	1.200	0	0.000	0	0.000	3
Carassius auratus	Goldfish ^	12	4.800	0	0.000	0	0.000	12
Nocomis biguttatus	Hornyhead Chub	1	0.400	1	0.003	6	0.019	8
Micropterus salmoides	Largemouth Bass	8	3.200	47	0.139	0	0.000	55
Percina caprodes	Logperch	7	2.800	231	0.681	8	0.025	246
Lepisosteus osseus	Longnose Gar	1	0.400	0	0.000	0	0.000	1
Notropis volucellus	Mimic Shiner	1	0.400	17	0.050	0	0.000	18
Esox masquinongy	Muskellunge	0	0.000	1	0.003	0	0.000	1
Hypentelium nigricans	Northern Hog Sucker	1	0.400	0	0.000	0	0.000	1
Noturus stigmosus	Northern Madtom	0	0.000	0	0.000	1	0.003	1
Esox lucius	Northern Pike	3	1.200	0	0.000	0	0.000	3
Lepomis gibbosus	Pumpkinseed	19	7.600	44	0.130	0	0.000	63

TABLE 1 continued.

Scientific name	Common name	Electrofishing (Night)		Paired Fyke Net		Minnow Trap Array		Total
		Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	
Oncorhynchus mykiss	Rainbow Trout^	1	0.400	0	0.000	0	0.000	1
Nocomis micropogon	River Chub	3	1.200	0	0.000	0	0.000	3
Ambloplites rupestris	Rock Bass	21	8.400	173	0.510	33	0.102	227
Neogobius melanostoma	Round Goby ^	3	1.200	172	0.507	206	0.639	381
Notropis stramineus	Sand Shiner	0	0.000	11	0.032	0	0.000	11
Moxostoma anisurum	Silver Redhorse	3	1.200	0	0.000	0	0.000	3
Micropterus dolomieu	Smallmouth Bass	24	9.600	174	0.513	2	0.006	200
Notropis hudsonius	Spottail Shiner	4	1.600	229	0.675	0	0.000	233
Minytrema melanops	Spotted Sucker	1	0.400	2	0.006	0	0.000	3
Proterorhinus marmoratus	Tubenose Goby ^	0	0.000	3	0.009	0	0.000	3
Sander vitreus	Walleye	7	2.800	1	0.003	0	0.000	8
Morone chrysops	White Bass	1	0.400	1	0.003	0	0.000	2
Morone americana	White Perch ^	0	0.000	10	0.029	0	0.000	10
Catostomus commersonii	White Sucker	3	1.200	1	0.003	0	0.000	4
Ameiurus natalis	Yellow Bullhead	0	0.000	2	0.006	0	0.000	2
Perca flavescens	Yellow Perch	48	19.200	24	0.067	31	0.096	103
	Total	573		2,051		304		2,928

* Sampling effort for electrofishing was 2.5 hours, paired fyke nets was 339.1 hours, and minnow trap arrays was 322.6 hours.

^ Species not native to the Lake Erie watershed according to Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE 2. Catch summary for juvenile and adult fish species captured from Maumee Bay during 2016.

Scientific name	Common name	Electrofishing (Night)		Paired Fyke Net		Bottom Trawl	Total
		Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	Number collected	
Ictiobus cyprinellus	Bigmouth Buffalo^	1	0.400	0	0.000	0	1
Ameiurus melas	Black Bullhead	0	0.000	9	0.027	0	9
Notropis heterolepis	Blacknose Shiner	0	0.000	1	0.003	0	1
Lepomis macrochirus	Bluegill	16	6.400	1,278	3.803	3	1,297
Pimephales notatus	Bluntnose Minnow	1	0.400	0	0.000	0	1
Amia calva	Bowfin	0	0.000	1	0.003	0	1
Labidesthes sicculus	Brook Silverside	28	11.200	0	0.000	7	35
Ameiurus nebulosus	Brown Bullhead	1	0.400	10	0.030	1	12
Ictalurus punctatus	Channel Catfish	0	0.000	40	0.119	3	43
Cyprinus carpio	Common Carp ^	3	1.200	1	0.003	0	4
Luxilus cornutus	Common Shiner	0	0.000	3	0.009	0	3
Notropis atherinoides	Emerald Shiner	12	4.800	2	0.006	2	16
Aplodinotus grunniens	Freshwater Drum	5	2.000	34	0.101	3	42
Dorosoma cepedianum	Gizzard Shad	542	216.800	15	0.045	30	587
Notemigonus crysoleucas	Golden Shiner	0	0.000	1	0.003	0	1
Carassius auratus	Goldfish ^	13	5.200	0	0.000	0	13
Micropterus salmoides	Largemouth Bass	2	0.800	1	0.003	0	3
Percina caprodes	Logperch	0	0.000	14	0.042	0	14
Lepisosteus osseus	Longnose Gar	0	0.000	3	0.009	0	3
Notropis volucellus	Mimic Shiner	5	2.000	10	0.030	629	644
Esox lucius	Northern Pike	1	0.400	0	0.000	0	1
Lepomis gibbosus	Pumpkinseed	17	6.800	152	0.452	5	174
Carpiodes cyprinus	Quillback	0	0.000	1	0.003	0	1
Ambloplites rupestris	Rock Bass	0	0.000	1	0.003	0	1
Neogobius melanostoma	Round Goby ^	0	0.000	117	0.348	32	149
Notropis stramineus	Sand Shiner	4	1.600	13	0.039	0	17
Macrhybopsis storeriana	Silver Chub	0	0.000	0	0.000	12	12
Micropterus dolomieu	Smallmouth Bass	1	0.400	1	0.003	2	4
Notropis hudsonius	Spottail Shiner	2	0.800	353	1.050	435	790
Percopsis omiscomaycus	Trout-perch	0	0.000	2	0.006	169	171

TABLE 2 continued.

Scientific name	Common name	Electrofishing (Night) Number collected	Electrofishing (Night) CPUE (fish/hr)*	Paired Fyke Net Number collected	Paired Fyke Net CPUE (fish/hr)*	Bottom Trawl Number collected	Total
Sander vitreus	Walleye	28	11.200	1	0.003	35	64
Morone chrysops	White Bass	1	0.400	23	0.068	3	27
Pomoxis annularis	White Crappie	0	0.000	2	0.006	0	2
Morone americana	White Perch ^	24	9.600	811	2.413	1,569	2,404
Catostomus commersonii	White Sucker	0	0.000	3	0.009	0	3
Ameiurus natalis	Yellow Bullhead	2	0.800	0	0.000	0	2
Perca flavescens	Yellow Perch	17	6.800	142	0.423	119	278
	Total	726		3,045		3,059	6,830

* Sampling effort for electrofishing was 2.5 hours, paired fyke nets was 336.0 hours and bottom trawls was 1.3 hours.
^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE 3. Catch summary for juvenile and adult fish species captured from Sandusky Bay during 2016.

Scientific name	Common name	Electrofishing (Night)		Paired Fyke Net		Bottom Trawl	Total
		Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	Number collected	
Ictiobus cyprinellus	Bigmouth Buffalo^	0	0.000	0	0.000	10	10
Ameiurus melas	Black Bullhead	1	0.400	16	0.050	0	17
Pomoxis nigromaculatus	Black Crappie	0	0.000	6	0.019	1	7
Lepomis macrochirus	Bluegill	11	4.400	10	0.031	1	22
Pimephales notatus	Bluntnose Minnow	2	0.800	0	0.000	0	2
Labidesthes sicculus	Brook Silverside	10	4.000	0	0.000	0	10
Ameiurus nebulosus	Brown Bullhead	0	0.400	18	0.056	0	18
Ictalurus punctatus	Channel Catfish	0	0.000	68	0.212	14	82
Cyprinus carpio	Common Carp ^	1	0.400	1	0.003	3	5
Notropis atherinoides	Emerald Shiner	4	1.600	5	0.016	1	10
Aplodinotus grunniens	Freshwater Drum	1	0.400	21	0.065	34	56
Dorosoma cepedianum	Gizzard Shad	447	178.800	41	0.128	26	514
Notemigonus crysoleucas	Golden Shiner	10	4.000	0	0.000	0	10
Carassius auratus	Goldfish ^	9	3.600	2	0.006	0	11
Micropterus salmoides	Largemouth Bass	1	0.400	0	0.000	0	1
Notropis volucellus	Mimic Shiner	0	0.000	7	0.022	125	132
Lepomis humilis	Orangespotted Sunfish^	0	0.000	3	0.009	0	3
Lepomis gibbosus	Pumpkinseed	6	2.400	3	0.009	1	10
Osmerus mordax	Rainbow Smelt ^	0	0.000	0	0.000	16	16
Neogobius melanostoma	Round Goby ^	0	0.000	1	0.003	6	7
Notropis stramineus	Sand Shiner	0	0.000	4	0.012	0	4
Macrhybopsis storeriana	Silver Chub	0	0.000	0	0.000	1	1
Micropterus dolomieu	Smallmouth Bass	0	0.000	0	0.000	2	2
Notropis hudsonius	Spottail Shiner	8	3.200	5	0.016	0	13
Percopsis omiscomaycus	Trout-perch	0	0.000	0	0.000	2	2
Sander vitreus	Walleye	9	3.600	1	0.003	25	35
Morone chrysops	White Bass	1	0.400	9	0.028	4	14
Morone chrysops x Morone americana	White Bass/White Perch Hybrid	0	0.000	0	0.000	2	2
Pomoxis annularis	White Crappie	0	0.000	126	0.393	2	128

TABLE 3 continued.

Scientific name	Common name	Electrofishing (Night) Number collected	Electrofishing (Night) CPUE (fish/hr)*	Paired Fyke Net Number collected	Paired Fyke Net CPUE (fish/hr)*	Bottom Trawl Number collected	Total
Morone americana	White Perch ^	82	32.800	783	2.440	1,954	2,819
Ameiurus natalis	Yellow Bullhead	0	0.000	8	0.025	0	8
Perca flavescens	Yellow Perch	36	14.400	29	0.090	80	145
	Total	639		1,167		2,310	4,116

* Sampling effort for electrofishing was 2.5 hours, paired fyke nets was 320.9 hours and bottom trawls was 1.3 hours.
^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE 4. Catch summary for juvenile and adult fish species captured from Buffalo and the upper Niagara River during 2016.

		Electrofishing (Day and Night)		Paired Fyke Net		Bottom Trawl	
Scientific name	Common name	Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	Number collected	Total
Alosa pseudoharengus	Alewife ^	1	0.137	1	0.004	0	2
Fundulus diaphanus	Banded Killifish	22	3.022	9	0.035	0	31
Pomoxis nigromaculatus	Black Crappie	0	0.000	1	0.004	0	1
Notropis heterolepis	Blacknose Shiner	0	0.000	4	0.016	0	4
Alosa aestivalis	Blueback Herring ^	6	0.824	0	0.000	0	6
Lepomis macrochirus	Bluegill	59	8.104	456	1.780	3	518
Pimephales notatus	Bluntnose Minnow	206	28.297	703	2.744	0	909
Amia calva	Bowfin	3	0.412	3	0.012	0	6
Labidesthes sicculus	Brook Silverside	44	6.044	2	0.008	0	46
Ameiurus nebulosus	Brown Bullhead	45	6.181	19	0.074	0	64
Cyprinus carpio	Common Carp ^	34	4.670	1	0.004	0	35
Luxilus cornutus	Common Shiner	0	0.000	2	0.008	0	2
Notropis atherinoides	Emerald Shiner	113	15.522	279	1.089	0	392
Pimephales promelas	Fathead Minnow	10	1.374	1	0.004	0	11
Aplodinotus grunniens	Freshwater Drum	5	0.687	0	0.000	0	5
Dorosoma cepedianum	Gizzard Shad	99	13.599	20	0.078	0	119
Moxostoma erythrurum	Golden Redhorse	13	1.786	7	0.027	0	20
Notemigonus crysoleucas	Golden Shiner	3	0.412	0	0.000	0	3
Carassius auratus	Goldfish ^	19	2.610	1	0.004	0	20
Moxostoma valenciennesi	Greater Redhorse	61	8.379	0	0.000	0	61
Nocomis biguttatus	Hornyhead Chub	13	1.786	0	0.000	0	13
Etheostoma exile	Iowa Darter	2	0.275	0	0.000	0	2
Micropterus salmoides	Largemouth Bass	117	16.071	34	0.133	0	151
Percina caprodes	Logperch	17	2.335	2	0.008	0	19
Esox masquinongy	Muskellunge	2	0.275	0	0.000	0	2
Hypentelium nigricans	Northern Hog Sucker	6	0.824	0	0.000	0	6
Esox lucius	Northern Pike	4	0.549	0	0.000	0	4
Lepomis gibbosus	Pumpkinseed	33	4.533	145	0.566	0	178
Carpiodes cyprinus	Quillback	2	0.275	0	0.000	0	2

TABLE 4 continued.

Scientific name	Common name	Electrofishing (Day and Night) Number collected	Electrofishing (Day and Night) CPUE (fish/hr)*	Paired Fyke Net Number collected	Paired Fyke Net CPUE (fish/hr)*	Bottom Trawl Number collected	Total
Oncorhynchus mykiss	Rainbow Trout ^	1	0.137	0	0.000	0	1
Ambloplites rupestris	Rock Bass	73	10.027	252	0.984	0	325
Neogobius melanostoma	Round Goby ^	33	4.533	47	0.183	3	83
Scardinius erythrophthalmus	Rudd ^	16	2.198	50	0.195	0	66
Moxostoma macrolepidotum	Shorthead Redhorse	11	1.511	0	0.000	0	11
Moxostoma anisurum	Silver Redhorse	47	6.456	0	0.000	0	47
Micropterus dolomieu	Smallmouth Bass	102	14.011	34	0.133	0	136
Cyprinella spiloptera	Spotfin Shiner	2	0.275	5	0.020	0	7
Notropis hudsonius	Spottail Shiner	115	15.797	322	1.257	5	442
Luxilus chrysocephalus	Striped Shiner	6	0.824	3	0.012	0	9
Sander vitreus	Walleye	10	1.374	7	0.027	1	18
Morone chrysops	White Bass	0	0.000	1	0.004	0	1
Morone americana	White Perch ^	1	0.137	6	0.023	0	7
Catostomus commersonii	White Sucker	445	61.126	26	0.101	0	471
Perca flavescens	Yellow Perch	194	26.648	89	0.347	18	301
	Total	1,995		2,532		30	4,557

* Sampling effort for electrofishing was 7.28 hours, paired fyke nets was 256.18 hours, and bottom trawls was 1.17 hours.
^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE 5. Species richness, number of unique species, and efficiency for juvenile and adult sampling gears fished from 2013-2016 in the Detroit River, Maumee Bay, Sandusky Bay, and Buffalo/upper Niagara River (UNR).

Sampling Dataset	Observed Species Richness	Unique Species	Estimated Species Richness	95% of Species Richness	Estimated Samples to Reach 95%	Sampling Efficiency (%)
Detroit River						
All Gears	57	-	60	56.98	133-134	95.0
Fyke net	46	9	56	53.15	140-141	82.2
Electrofish	46	10	58	54.96	68-69	79.5
Minnow trap (2014-2016)	14	1	16	15.39	78-79	86.4
Maumee Bay						
All Gears	48	-	51	48.49	154-155	94.0
Fyke net	45	17	50	47.48	83-84	90.0
Electrofish (2014, 2016)	23	2	26	25.13	37-38	87.0
Bottom trawl	23	1	29	27.46	143-144	79.6
Sandusky Bay						
All Gears	41	-	91	86.14	1972-1973	45.2
Fyke net	27	3	39	37.28	263-264	68.8
Electrofish (2013-2014, 2016)	28	6	58	54.70	328-329	48.6
Bottom trawl	27	4	45	42.47	427-428	60.4
Buffalo/UNR						
All Gears	62	-	77	73.20	616-617	80.5
Fyke net (2015-2016)	46	5	52	49.26	43-44	88.7
Electrofish	56	16	68	65.00	312-313	81.9
Bottom trawl	9	0	24	22.58	469-470	37.9

TABLE 6. Catch summary for ichthyoplankton collected from Maumee Bay during 2016. The identification of ichthyoplankton included screening for specific invasive species that were found not to be present (bottom portion of the table).

		Bongo Net (Night)		Light Trap (Night)		
Scientific name	Common name	Number collected	CPUE (fish/10 m³)*	Number collected	CPUE (fish/hr)*	Total
Fundulus diaphanus	Banded Killifish	0	0.000	4	0.151	4
Labidesthes sicculus	Brook Silverside	1	0.006	4	0.151	5
Ictiobus sp.	Buffalo species^	1	0.006	0	0.000	1
Ictalurus punctatus	Channel Catfish	2	0.013	0	0.000	2
Cyprinus carpio	Common Carp ^	3	0.019	0	0.000	3
Pomoxis sp.	Crappie species	0	0.000	14	0.528	14
Aplodinotus grunniens	Freshwater Drum	3	0.019	0	0.000	3
Dorosoma cepedianum	Gizzard Shad	921	5.980	7	0.264	928
Gobiidae sp.	Goby species ^	2	0.013	9	0.339	11
Lepomis sp.	Lepomis species	3	0.019	0	0.000	3
Percina caprodes	Logperch	89	0.578	6	0.226	95
Cyprinidae sp.	Minnow/Shiner species	61	0.396	5	0.188	66
Percidae sp.	Perch species	108	0.701	2	0.075	110
Carpiodes cyprinus	Quillback	2	0.013	1	0.038	3
Centrarchidae sp.	Sunfish species	10	0.065	1	0.038	11
Percopsis omiscomaycus	Trout-perch	1	0.006	1	0.038	2
N/A	Unidentifiable	153	0.993	2	0.075	155
Sander vitreus	Walleye	8	0.052	0	0.000	8
Morone sp.	White Bass/White Perch ^	4,784	31.063	5	0.188	4,789
Perca flavescens	Yellow Perch	676	4.389	5	0.188	681
	Total	6,828		66		6,894
Additional Invasive Species Vetted:						
Hypophthalmichthys nobilis	Bighead Carp^	0	0.000	0	0.000	0
Mylopharyngodon piceus	Black Carp^	0	0.000	0	0.000	0
Ctenopharyngodon idella	Grass Carp^	0	0.000	0	0.000	0
Hypophthalmichthys moltrix	Silver Carp^	0	0.000	0	0.000	0
	Total	0		0		0

* Sampling effort for bongo netting was 1540.1 m³ and light trapping was 26.5 hours.

^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE 7. Catch summary for ichthyoplankton collected from Sandusky Bay during 2016. The identification of ichthyoplankton included screening for specific invasive species that were found not to be present (bottom portion of the table).

		Bongo Net (Night)		Light Trap (Night)		
Scientific name	Common name	Number collected	CPUE (fish/10 m³)*	Number collected	CPUE (fish/hr)*	Total
Labidesthes sicculus	Brook Silverside	0	0.000	47	1.792	47
Ictalurus punctatus	Channel Catfish	0	0.000	1	0.038	1
Cyprinus carpio	Common Carp ^	2	0.010	0	0.000	2
Pomoxis sp.	Crappie species	1	0.005	0	0.000	1
Aplodinotus grunniens	Freshwater Drum	403	2.002	0	0.000	403
Dorosoma cepedianum	Gizzard Shad	1,146	5.693	1	0.038	1,147
Gobiidae sp.	Goby species ^	31	0.154	3	0.114	34
Lepomis sp.	Lepomis species	28	0.139	83	3.164	111
Percina caprodes	Logperch	1	0.005	1	0.038	2
Cyprinidae sp.	Minnow/Shiner species	142	0.705	5	0.191	147
Percidae sp.	Perch species	1	0.005	0	0.000	1
Osmerus mordax	Rainbow Smelt ^	1	0.005	0	0.000	1
Neogobius melanostomus	Round Goby ^	57	0.283	0	0.000	57
Centrarchidae sp.	Sunfish species	11	0.055	2	0.076	13
N/A	Unidentifiable	58	0.288	8	0.305	66
Morone sp.	White Bass/White Perch ^	291	1.446	0	0.000	291
Perca flavescens	Yellow Perch	2	0.010	0	0.000	2
	Total	2,175		151		2,326
Additional Invasive Species Vetted:						
Hypophthalmichthys nobilis	Bighead Carp^	0	0.000	0	0.000	0
Mylopharyngodon piceus	Black Carp^	0	0.000	0	0.000	0
Ctenopharyngodon idella	Grass Carp^	0	0.000	0	0.000	0
Hypophthalmichthys moltrix	Silver Carp^	0	0.000	0	0.000	0
	Total	0		0		0

* Sampling effort for bongo netting was 2,013.0 m³ and light trapping was 26.2 hours.

^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE 8. Catch summary for ichthyoplankton collected from Buffalo/upper Niagara River during 2016. The identification of ichthyoplankton included screening for specific invasive species that were found not to be present (bottom portion of the table).

		Bongo Net (Night)		Light Trap (Night)		
Scientific name	Common name	Number collected	CPUE (fish/10 m³)*	Number collected	CPUE (fish/hr)*	Total
Alosa pseudoharengus	Alewife ^	1	0.007	0	0.000	1
Lepomis macrochirus	Bluegill	0	0.000	20	0.369	20
Notropis atherinoides	Emerald Shiner	8	0.055	0	0.000	8
Aplodinotus grunniens	Freshwater Drum	2	0.014	0	0.000	2
Dorosoma cepedianum	Gizzard Shad	2	0.014	3	0.055	5
Micropterus salmoides	Largemouth Bass	0	0.000	4	0.074	4
Notropis volucellus	Mimic Shiner	1	0.007	0	0.000	1
Lepomis gibbosus	Pumpkinseed	0	0.000	8	0.148	8
Ambloplites rupestris	Rock Bass	1	0.007	0	0.000	1
Neogobius melanostoma	Round Goby ^	83	0.575	46	0.849	129
Sander vitreus	Walleye	1	0.007	0	0.000	1
Morone chrysops	White Bass	6	0.042	0	0.000	6
Morone sp.	White Bass/White Perch ^	2	0.014	0	0.000	2
Pomoxis annularis	White Crappie	0	0.000	2	0.037	2
Morone americana	White Perch ^	21	0.146	0	0.000	21
Perca flavescens	Yellow Perch	8	0.055	0	0.000	8
	Total	136		83		219
Additional Invasive Species Vetted:						
Hypophthalmichthys nobilis	Bighead Carp^	0	0.000	0	0.000	0
Mylopharyngodon piceus	Black Carp^	0	0.000	0	0.000	0
Gymnocephalus cernuus	Ruffe^	0	0.000	0	0.000	0
Ctenopharyngodon idella	Grass Carp^	0	0.000	0	0.000	0
Hypophthalmichthys moltrix	Silver Carp^	0	0.000	0	0.000	0
	Total	0		0		0

* Sampling effort for bongo netting was 1,443.02 m³ and light trapping was 54.15 hours.

^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE 9. Catch summary for benthos and amphipod species collected from Buffalo/upper Niagara River during 2016.

Scientific name	Common name	Number collected
Amphipoda		
Echinogammarus ischnus		659
Gammarus fasciatus		4
Bivalvia		
Pisidium sp.	Pea clams	8
Gastropoda		
Amnicola limosa	Mud Amnicola	1
Cincinnatia cincinnatiensis		147
Gyraulus circumstriatus	Disc Gyro	256
Hydrobiidae sp.	Mud Snails	2,912
Marstonia decepta		6
Physidae sp.	Bladder Snails	8
Physa gyrina		1
Physa integra		16
Probythinella lacustris		37
Somatogyrus subglobosus		1
Valvata piscinalis	European stream valvata	1
Valvata sincera	Mossy valvata	8
	Total	4,065

FIGURES

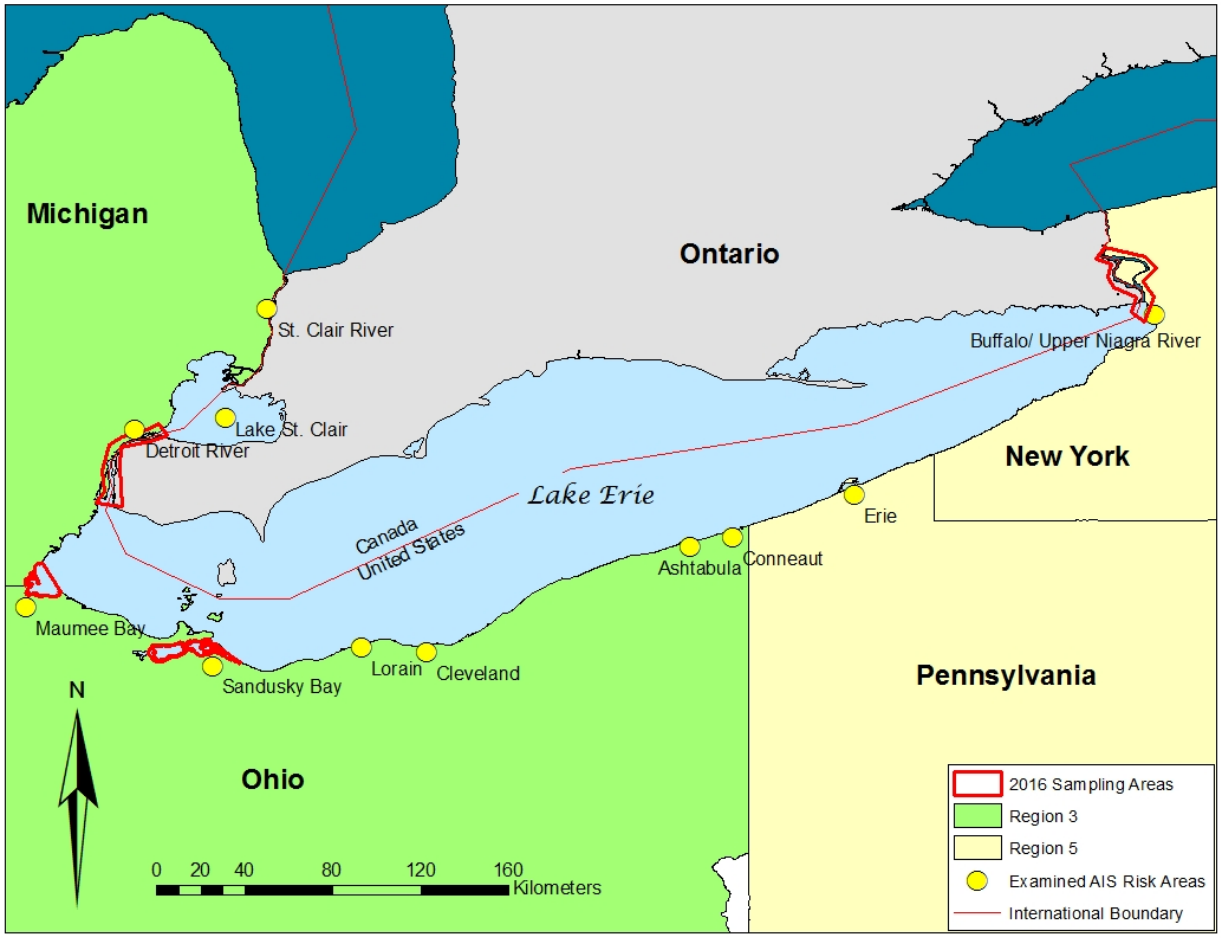


FIGURE 1. The Lake Erie Basin showing high risk areas and locations sampled during 2016.

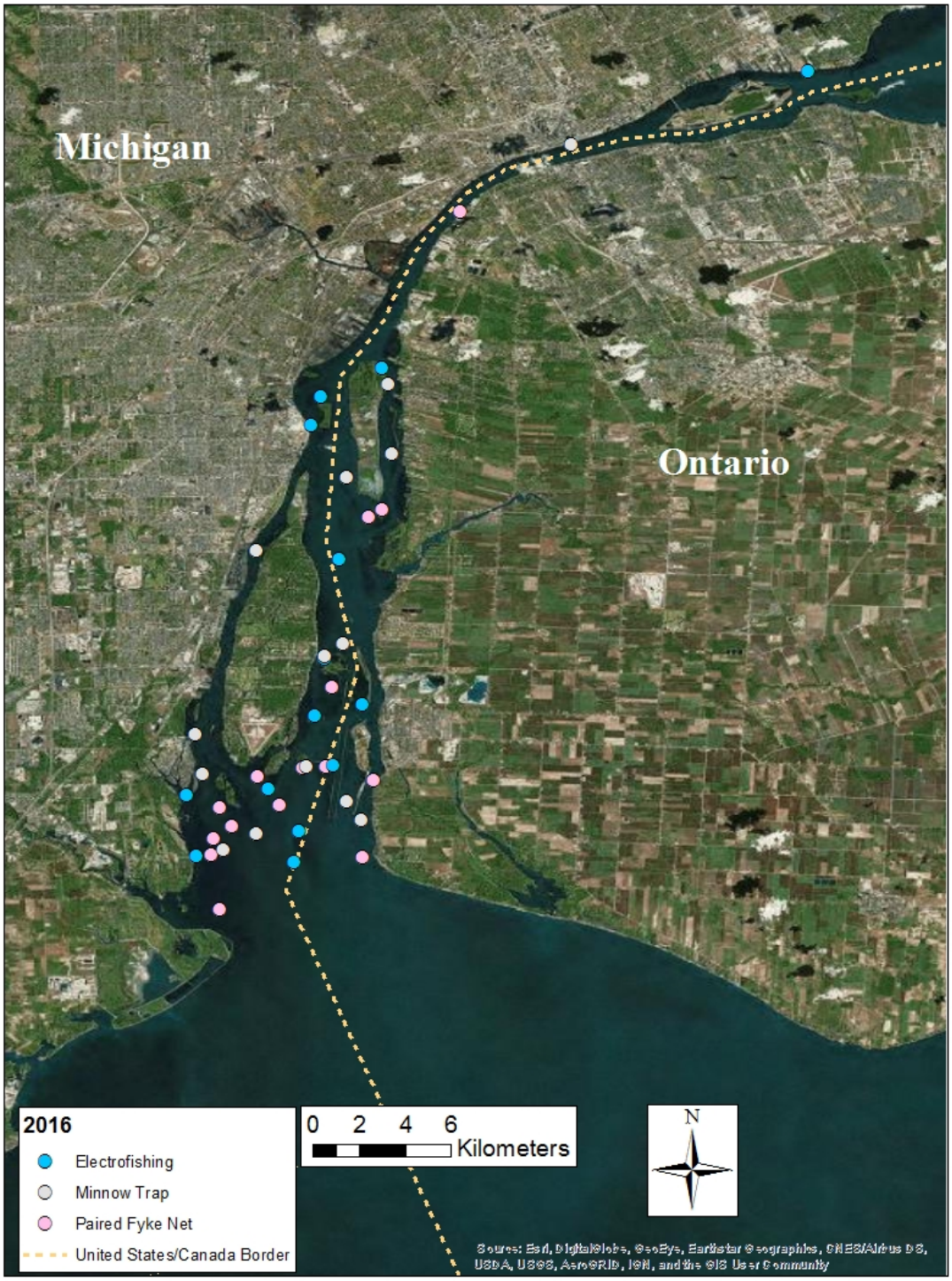


FIGURE 2. The Detroit River showing locations sampled for juvenile and adult fish during 2016.

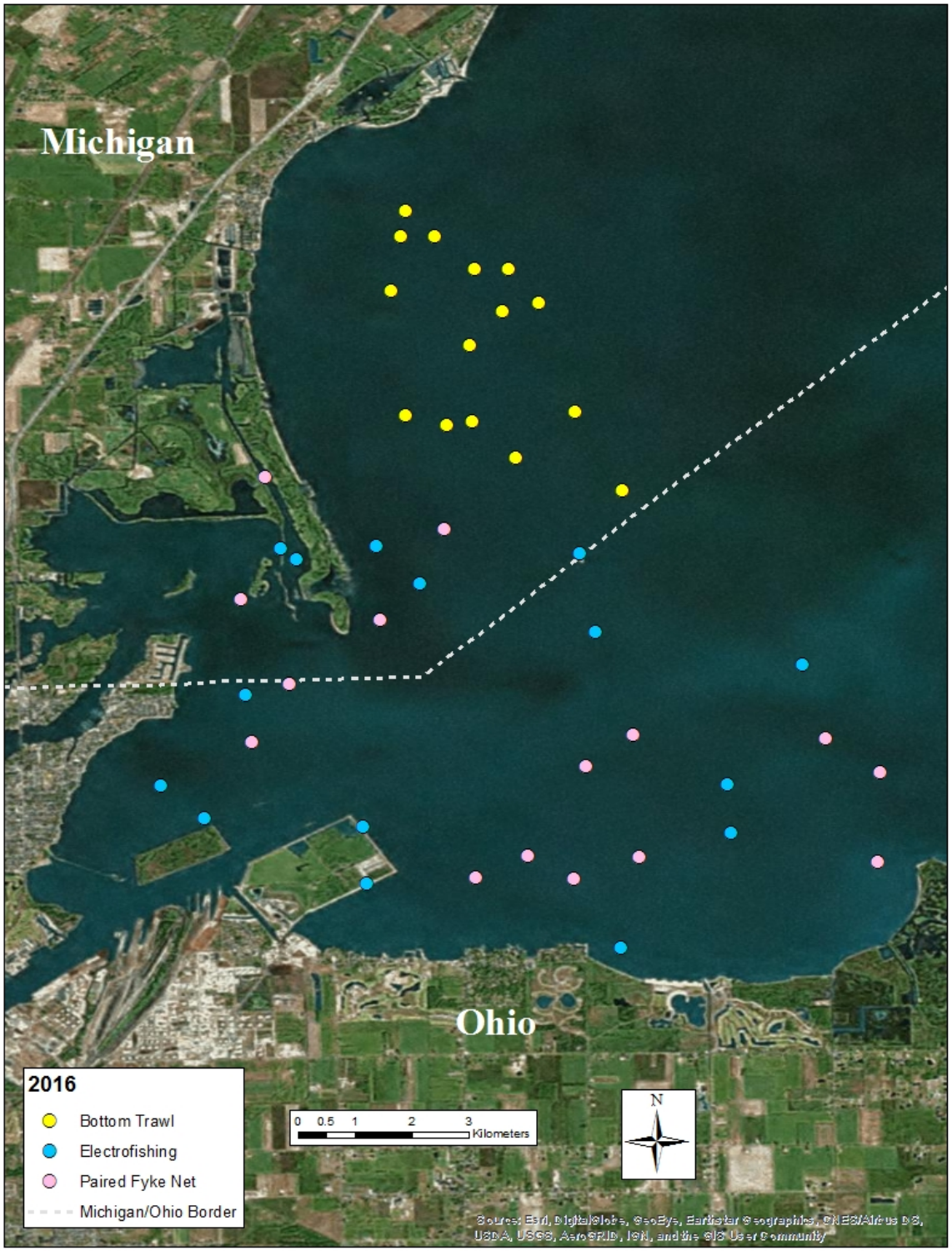


FIGURE 3. Maumee Bay showing locations sampled for juvenile and adult fish during 2016.

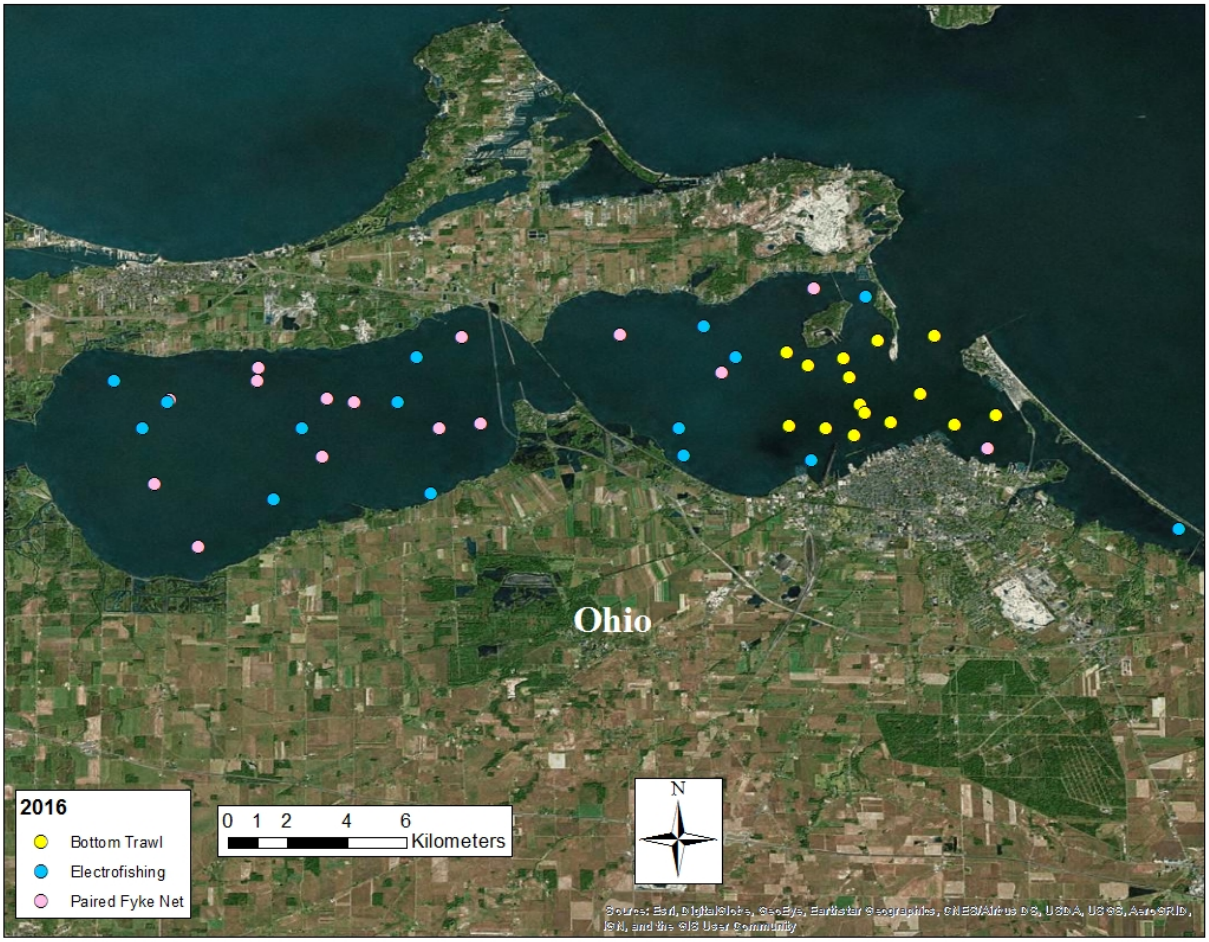


FIGURE 4. Sandusky Bay showing locations sampled for juvenile and adult fish during 2016.

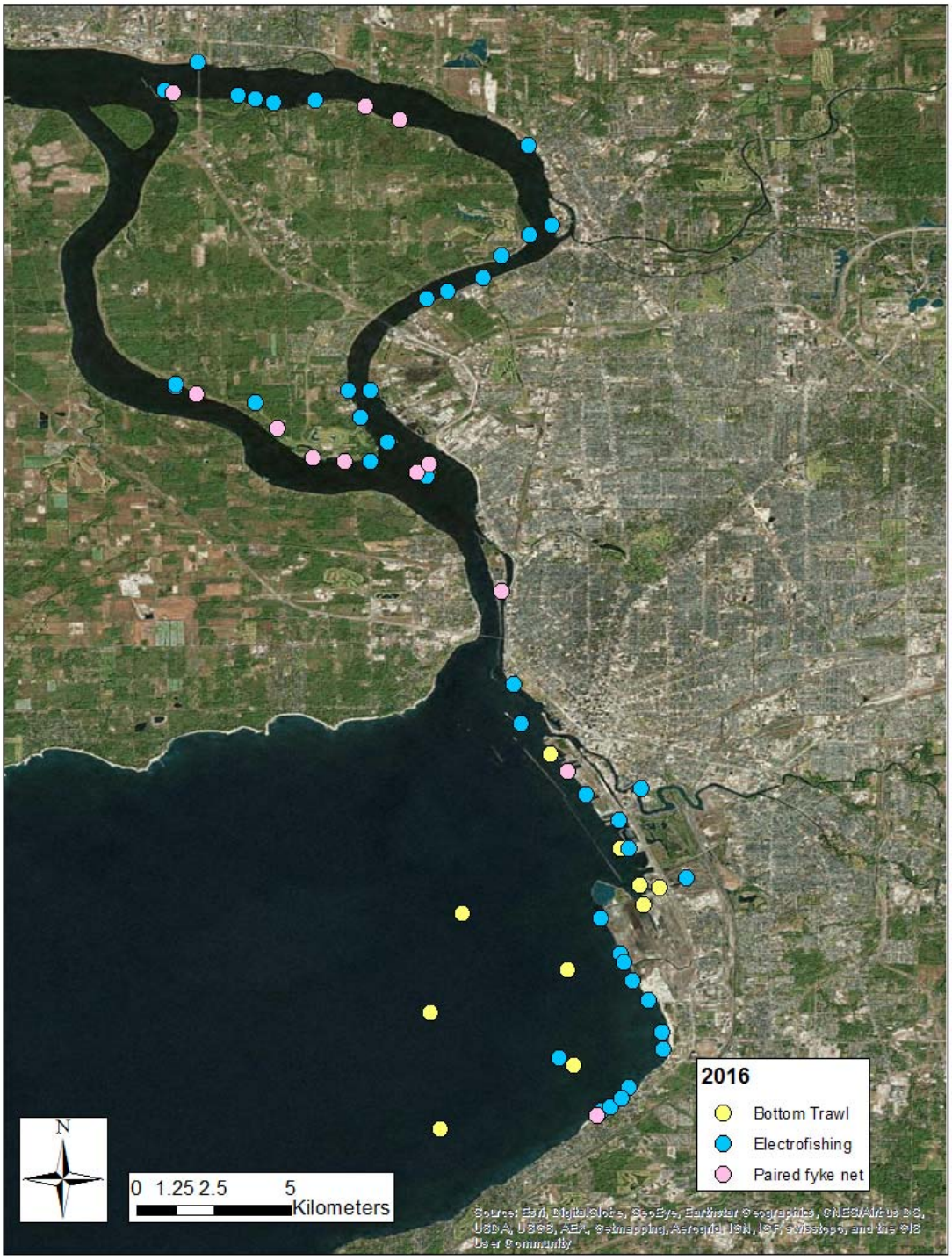


FIGURE 5. Buffalo, New York and the upper Niagara River showing locations sampled for juvenile and adult fish during 2016.

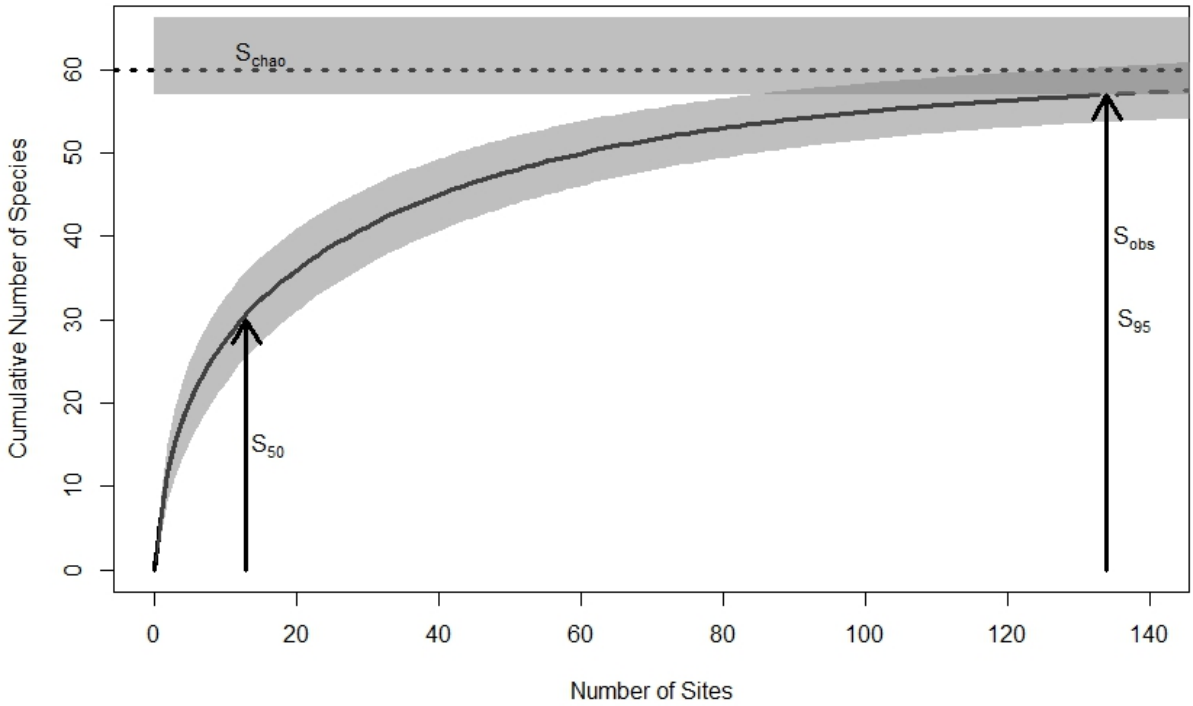


FIGURE 6. Species accumulation curves for all sampling gears fished for juvenile and adult fish combined in the Detroit River, 2013-2016. S_{chao} = total number of species estimated based on the Chao asymptotic richness estimator (horizontal dotted line). S_{50} = 50% of estimated number of total species. S_{95} = 95% of estimated number of total species. S_{obs} = total number of species caught. Shaded regions represent 95% confidence intervals.

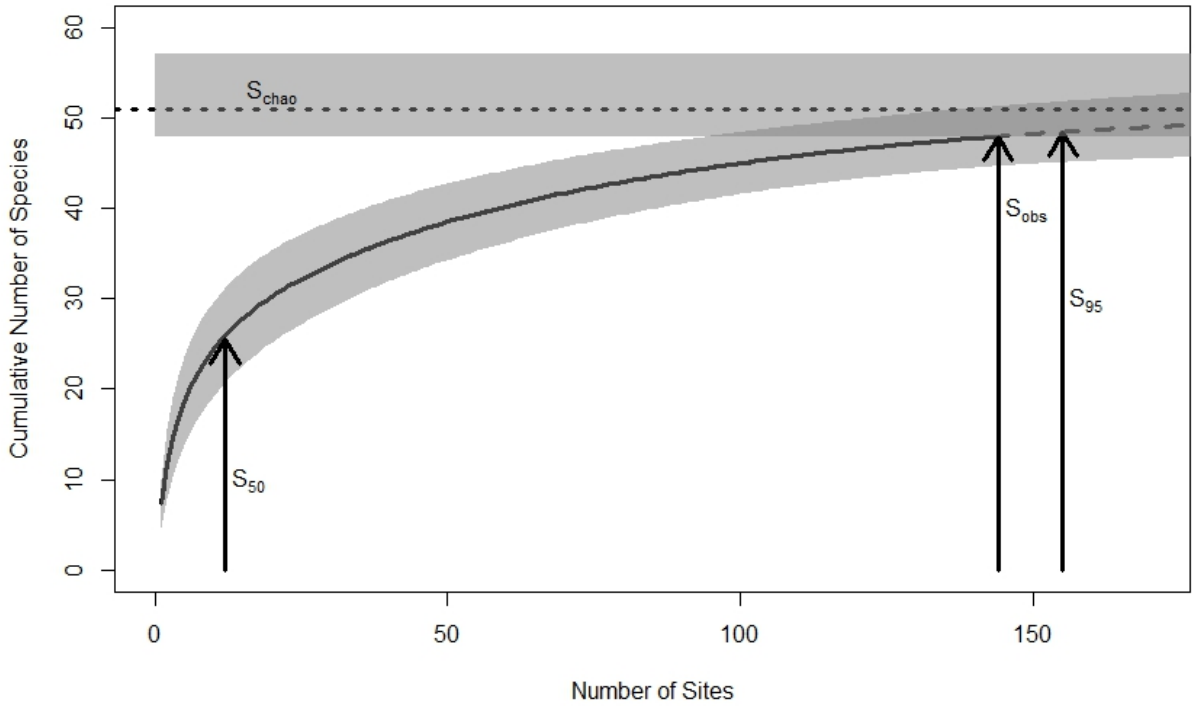


FIGURE 7. Species accumulation curves for all sampling gears fished for juvenile and adult fish combined in Maumee Bay, 2013-2016. S_{chao} = total number of species estimated based on the Chao asymptotic richness estimator (horizontal dotted line). S_{50} = 50% of estimated number of total species. S_{95} = 95% of estimated number of total species. S_{obs} = total number of species caught. Shaded regions represent 95% confidence intervals.

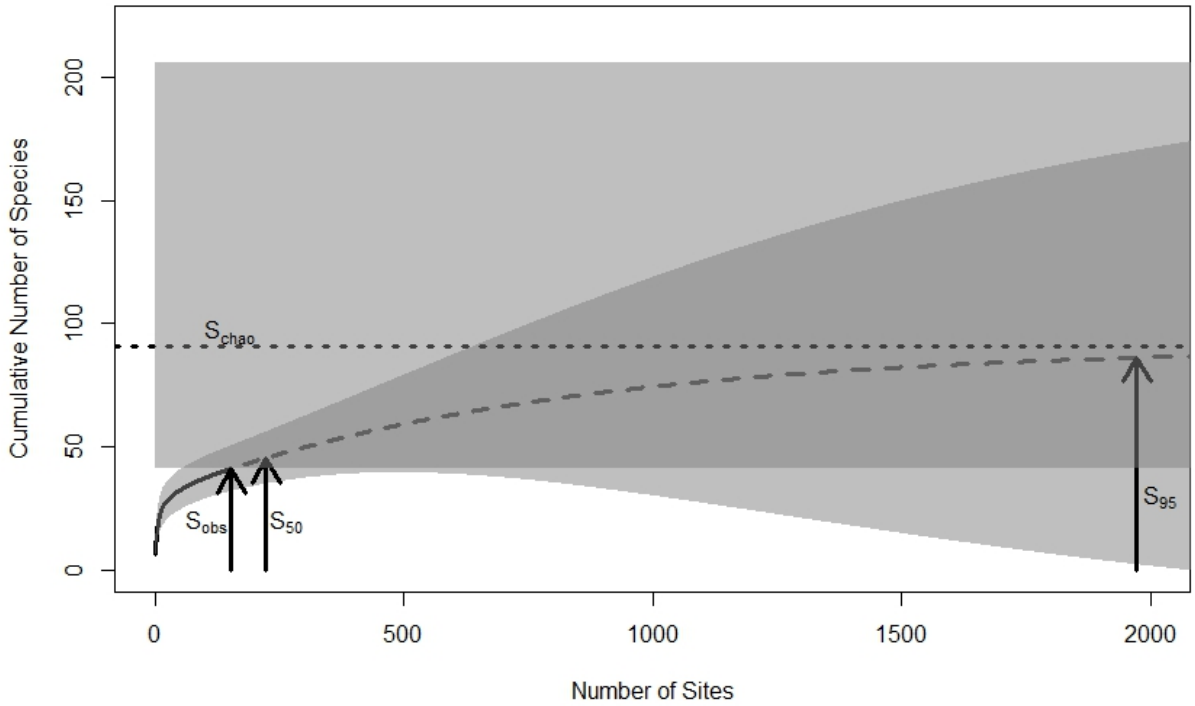


FIGURE 8. Species accumulation curves for all sampling gears fished for juvenile and adult fish combined in Sandusky Bay, 2013-2016. S_{chao} = total number of species estimated based on the Chao asymptotic richness estimator (horizontal dotted line). S_{50} = 50% of estimated number of total species. S_{95} = 95% of estimated number of total species. S_{obs} = total number of species caught. Shaded regions represent 95% confidence intervals.

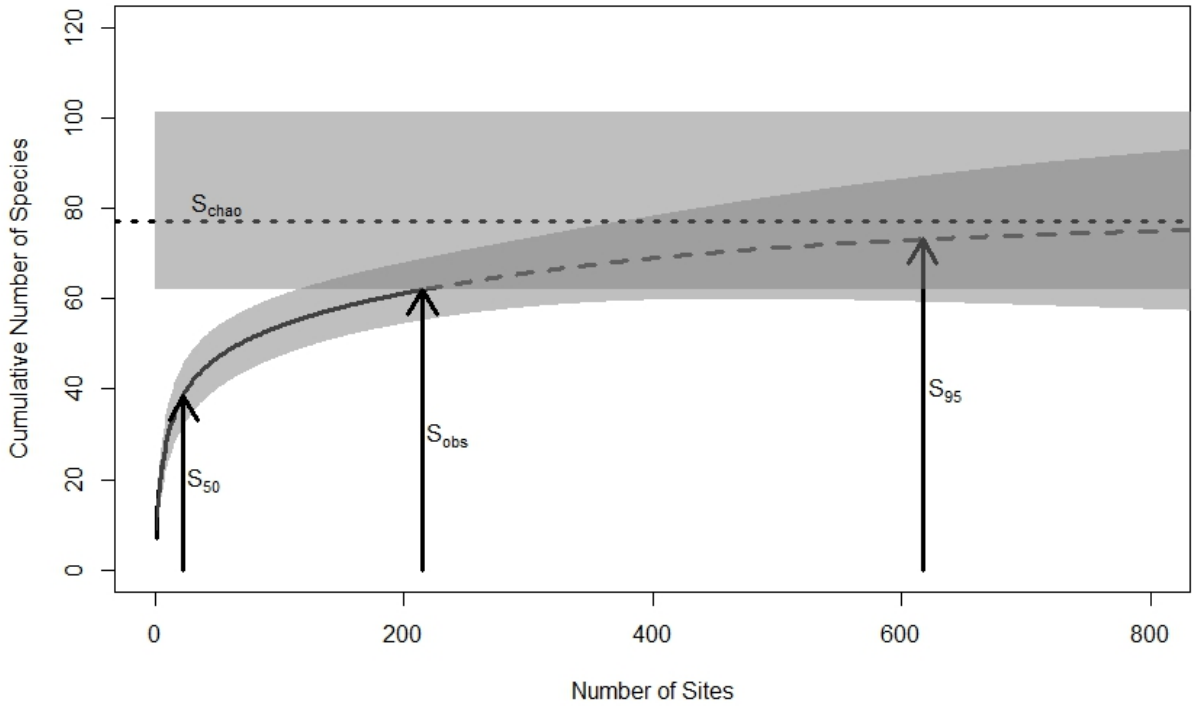


FIGURE 9. Species accumulation curves for all sampling gears fished for juvenile and adult fish combined in Buffalo and the upper Niagara River, 2013-2016. S_{chao} = total number of species estimated based on the Chao asymptotic richness estimator (horizontal dotted line). S_{50} = 50% of estimated number of total species. S_{95} = 95% of estimated number of total species. S_{obs} = total number of species caught. Shaded regions represent 95% confidence intervals.

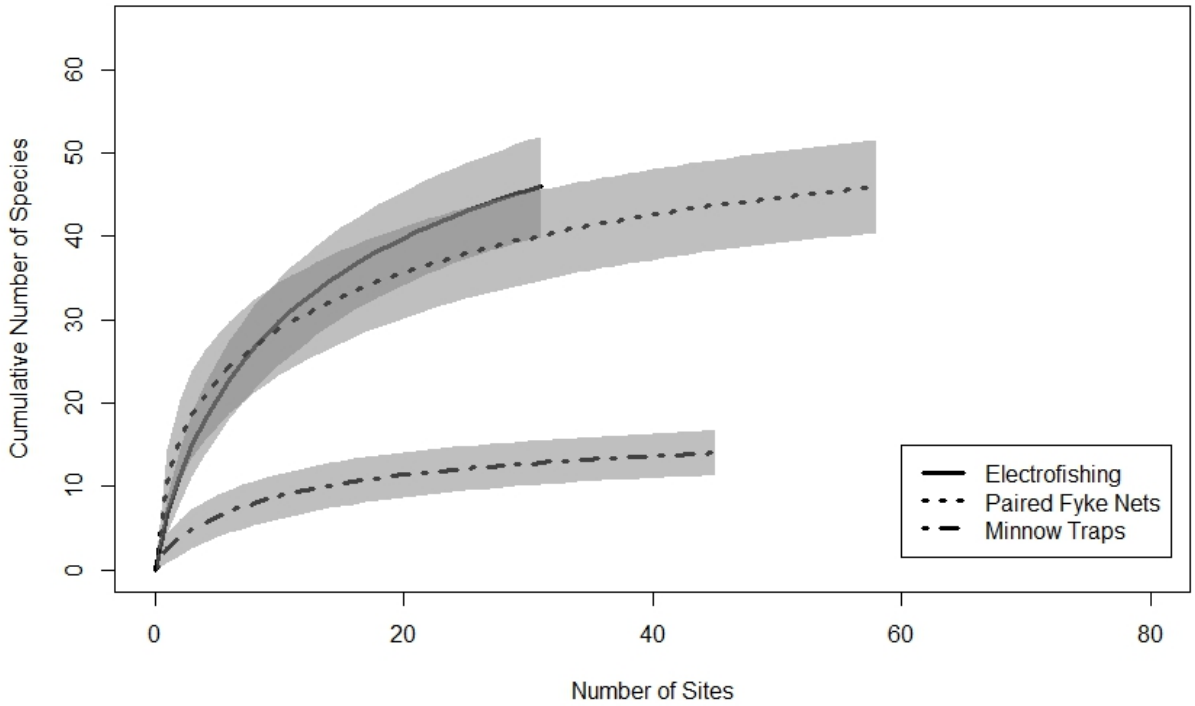


FIGURE 10. Species accumulation curve for sampling gears fished for juvenile and adult fish in the Detroit River, 2013-2016. Shaded areas represent 95% confidence intervals.

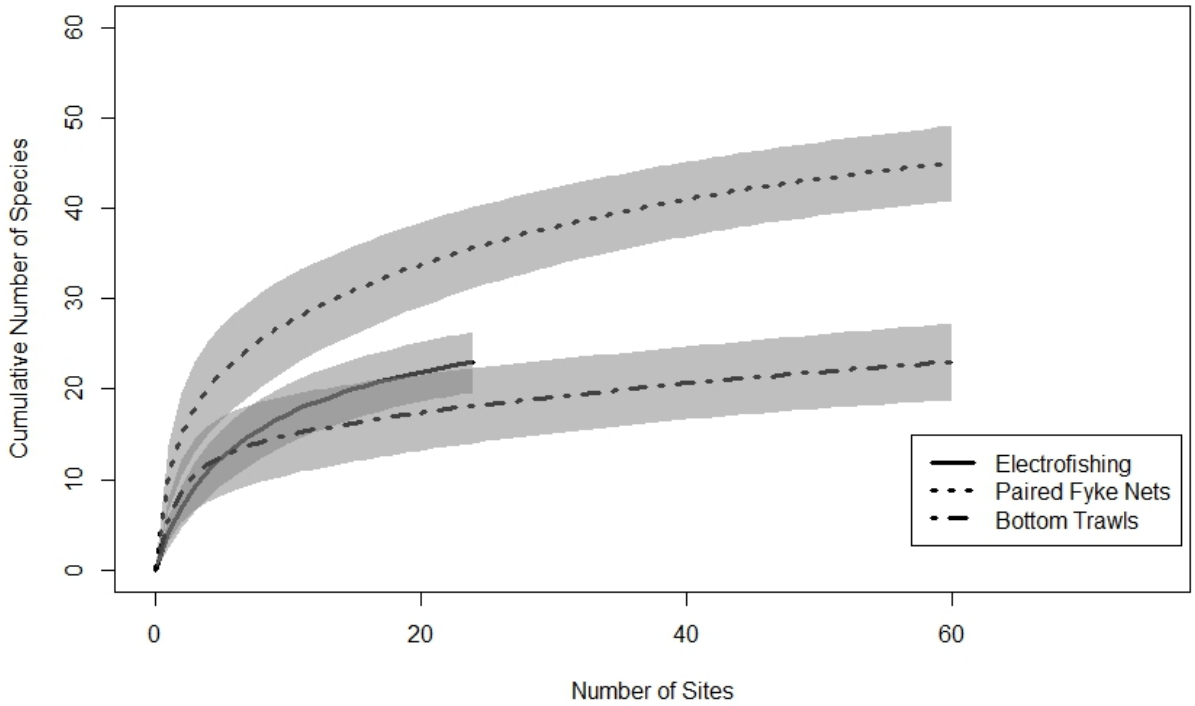


FIGURE 11. Species accumulation curve for sampling gears fished for juvenile and adult fish in Maumee Bay, 2013-2016. Shaded areas represent 95% confidence intervals.

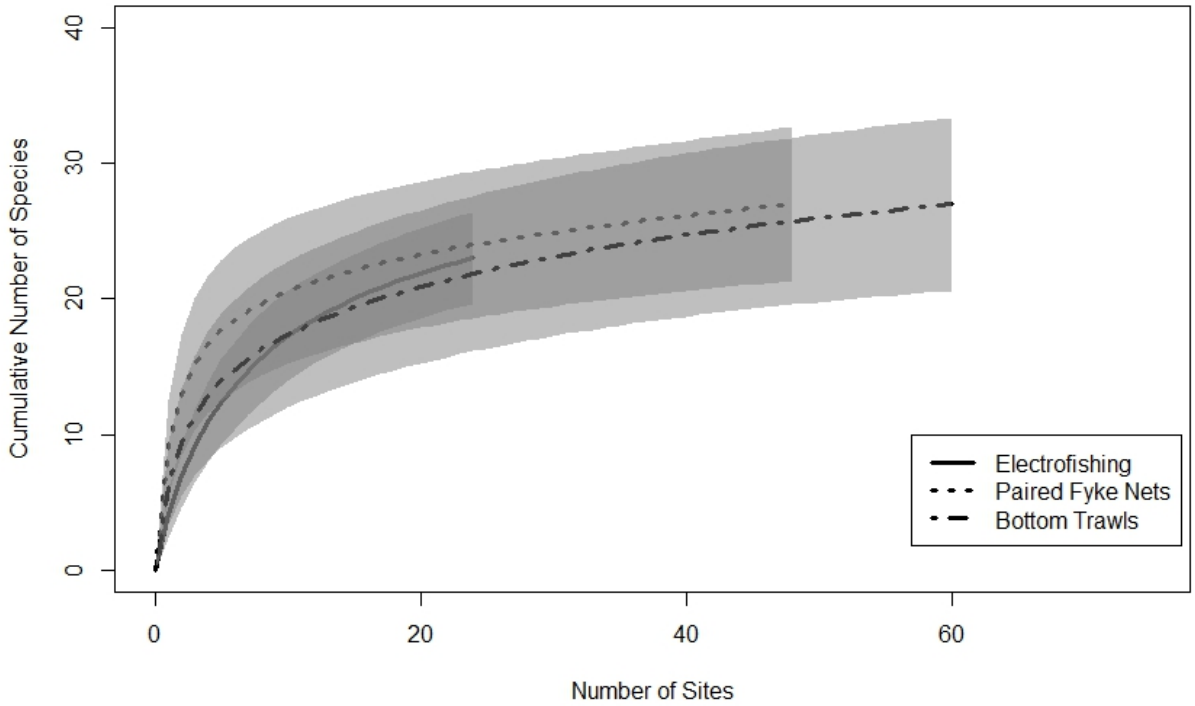


FIGURE 12. Species accumulation curve for sampling gears fished for juvenile and adult fish in Sandusky Bay, 2013-2016. Shaded areas represent 95% confidence intervals.

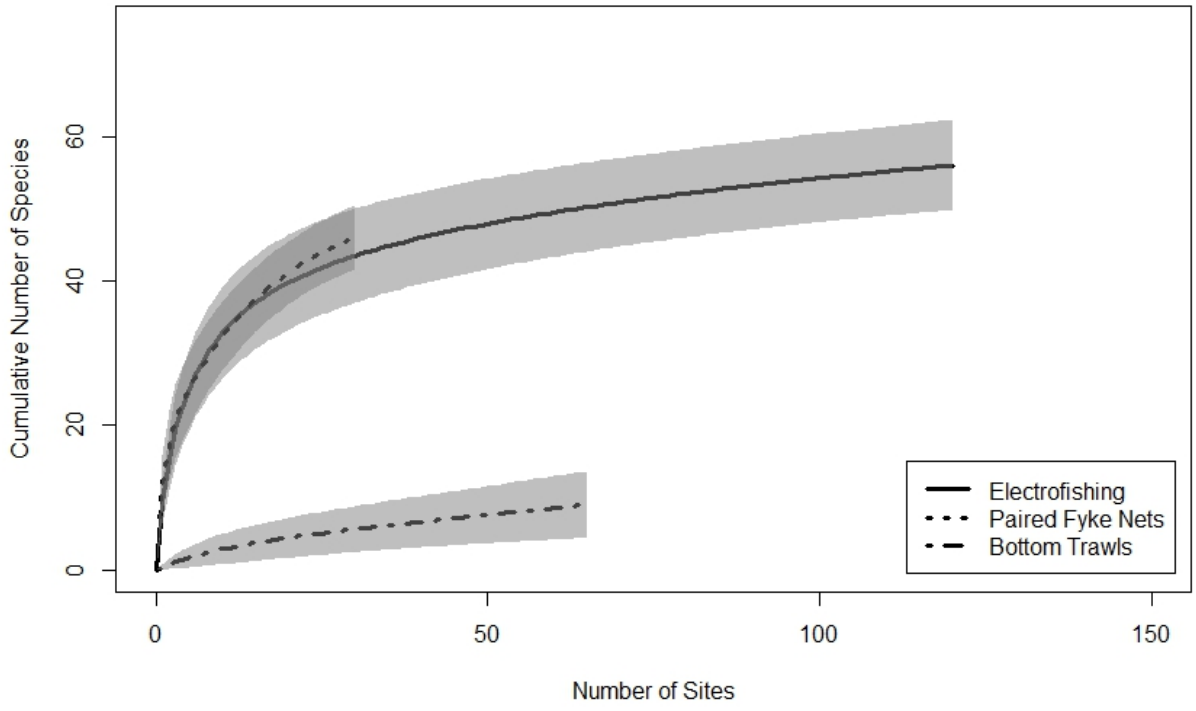


FIGURE 13. Species accumulation curve for sampling gears fished for juvenile and adult fish in Buffalo and the upper Niagara River, 2013-2016. Shaded areas represent 95% confidence intervals.

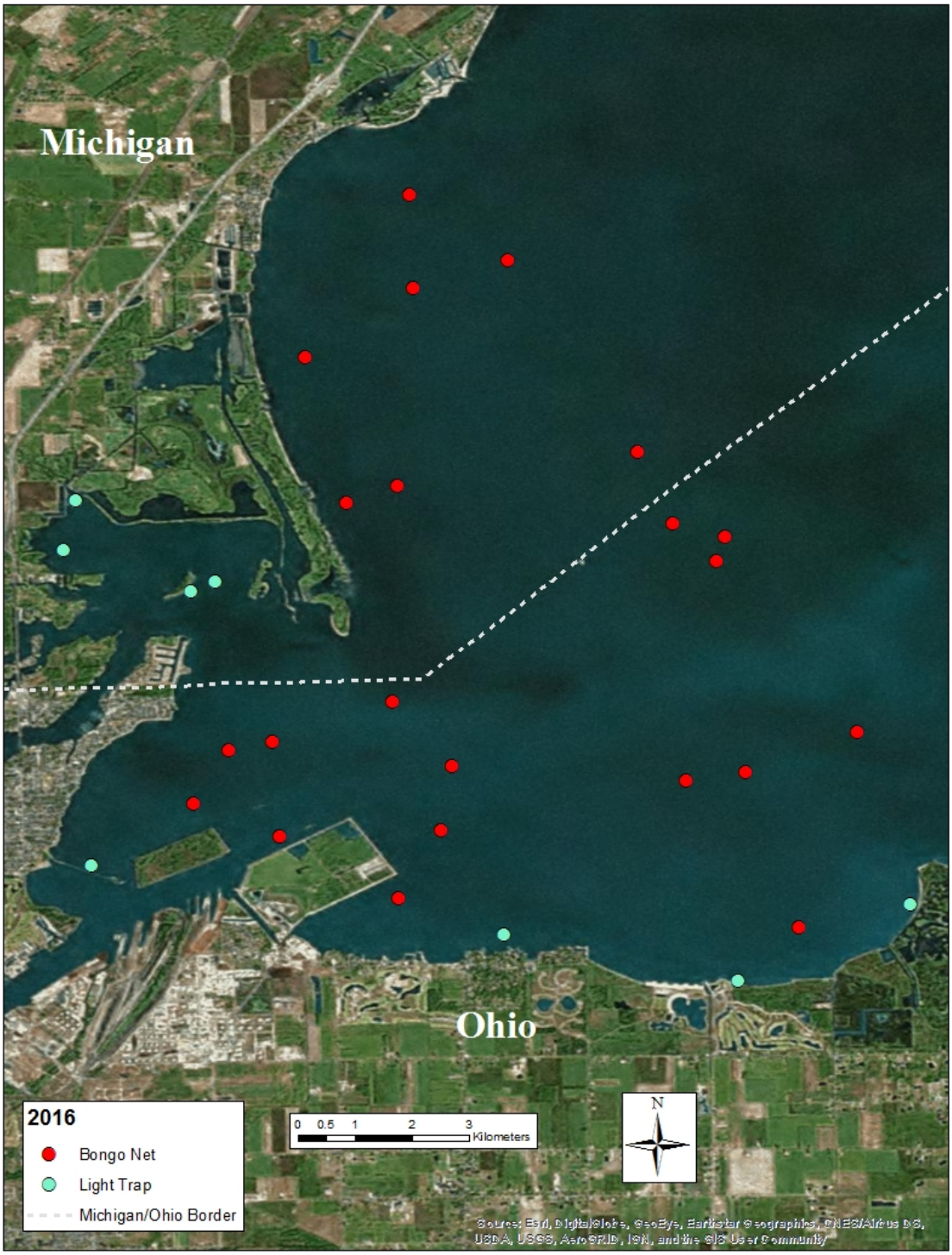


FIGURE 14. Maumee Bay showing locations sampled for ichthyoplankton during 2016.

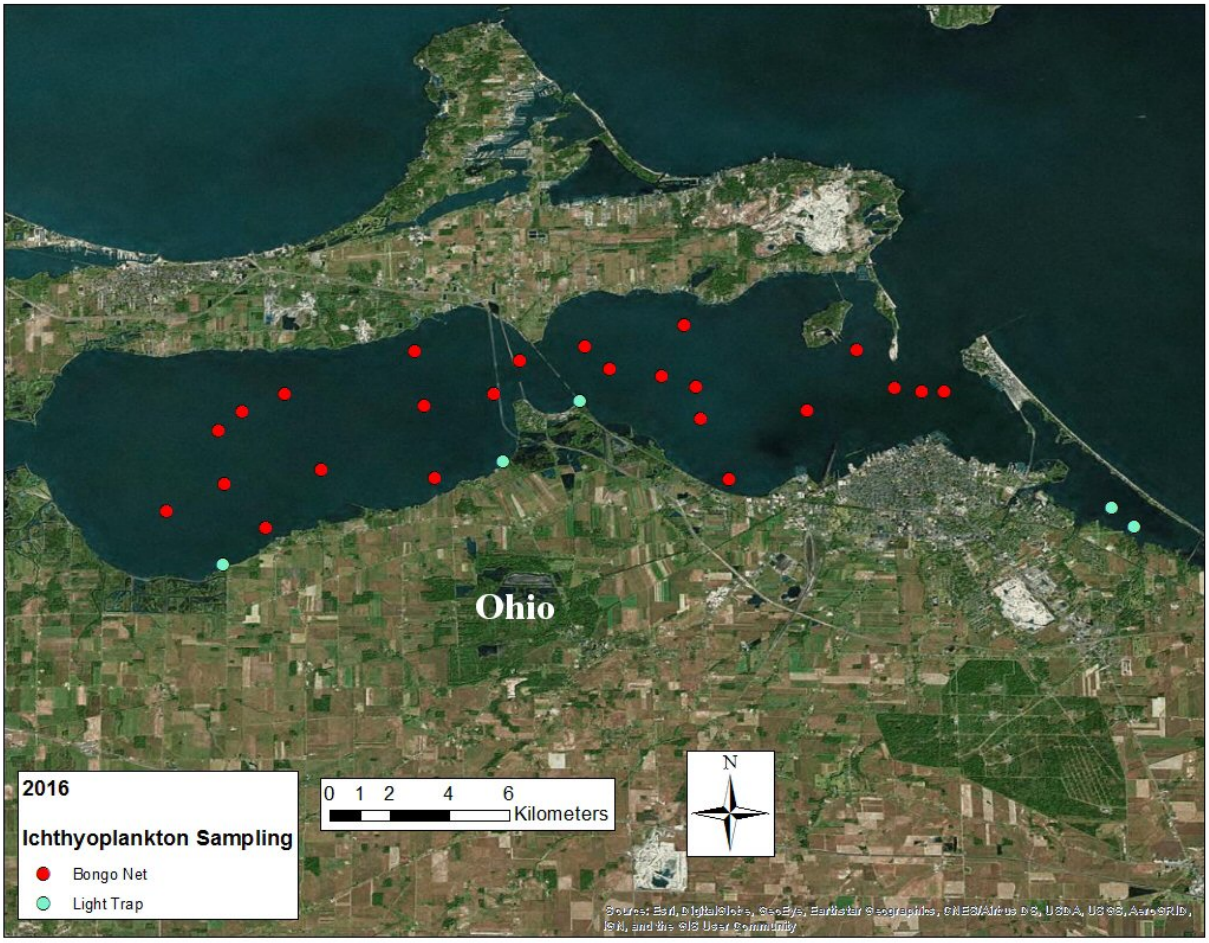


FIGURE 15. Sandusky Bay showing locations sampled for ichthyoplankton during 2016.

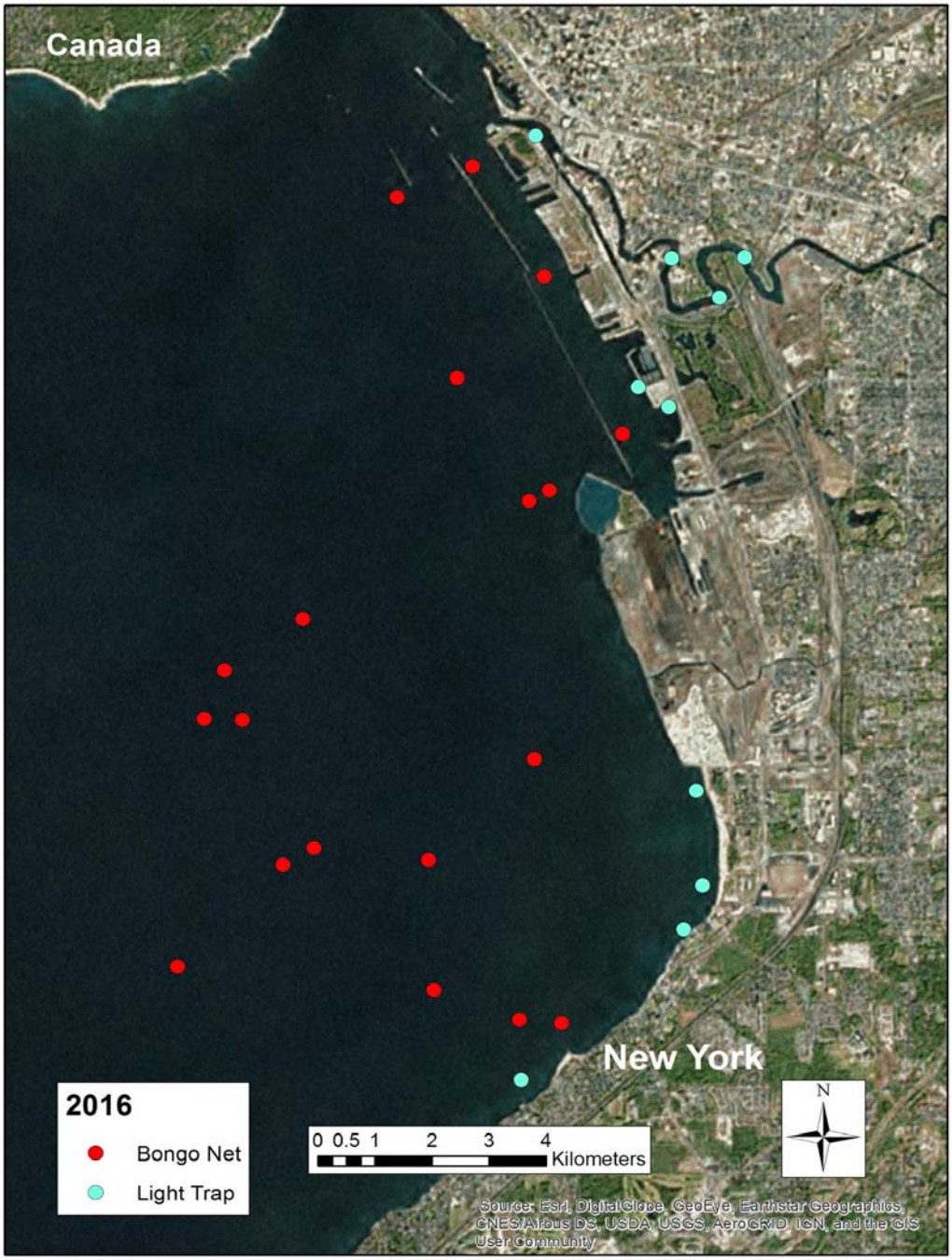


FIGURE 16. Buffalo and the Buffalo River showing locations sampled for ichthyoplankton during 2016.

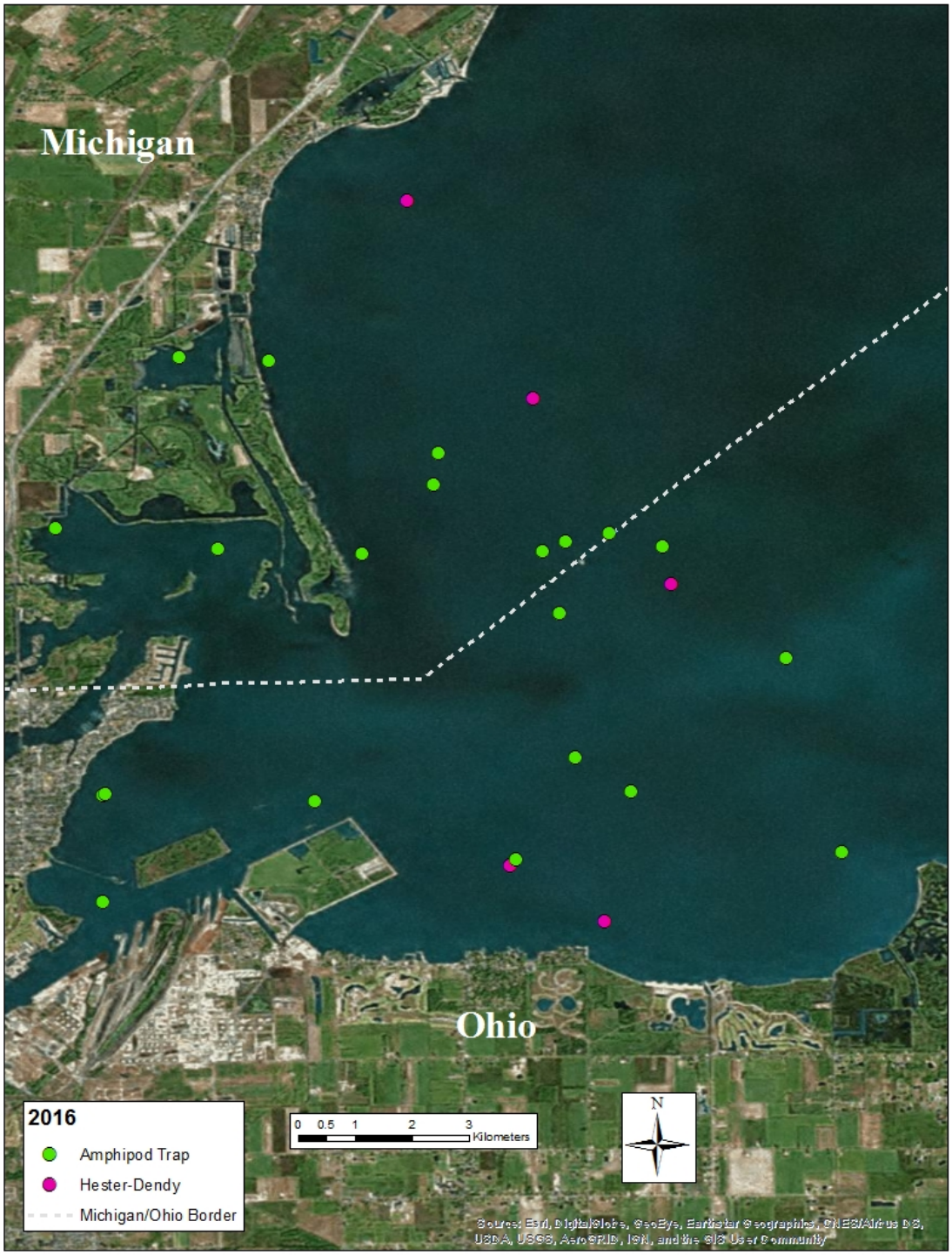


FIGURE 17. Maumee Bay showing locations sampled for benthic macroinvertebrates during 2016.

FIGURE 18. Buffalo and the upper Niagara River showing locations sampled for benthic macroinvertebrates during 2016.

APPENDICES

Appendix A – Pilot Study for the Early Detection of Non-Native Fishes in Presque Isle Bay in Erie, Pennsylvania.

Introduction

A pilot survey was conducted in Presque Isle Bay, located in Erie, Pennsylvania. The purpose of this survey was to familiarize biologists with a potential new survey area and to determine which gears may be effective within that area. The survey was conducted from October 17 through October 19, 2016. Data from the survey will be used to create gear-suitable maps for the random site selection tool which will be used in future sampling events at this location.

Study Area

Presque Isle Bay is located in Erie, Pennsylvania on the southern shore of Lake Erie at the eastern end of the central basin (Figure A-1). Presque Isle Bay was listed as an AOC as part of the Great Lakes Water Quality Agreement of 1987 due to pollution from sewage and industrial waste, but was removed from the list in 2013 due to the success of remediation activities. The Presque Isle Bay embayment has a surface area of 3,655 acres, is 7.4 km in length, 2.9 km at its widest point, and has an average depth of 4 m. The natural bay is formed and sheltered by a recurved peninsula that makes up Presque Isle State Park, a National Natural Landmark that attracts over four million visitors a year to recreate via swimming, boating, fishing, biking, and bird watching. The bay is bounded by Presque Isle on the west and north ends, and the easterly end of the bay has been dredged to create Erie Harbor with a connection to Lake Erie via shipping channel maintained by the Army Corps of Engineers. The bay shoreline is characterized by numerous small bays, coves, and inlets. Erie is Pennsylvania's primary access point to Great Lakes shipping routes, which caused the area to become a hub of heavy manufacturing industries. While total ballast discharged in the bay is low, it has a high proportion of ballast water sourced from overseas which increases the risk of a non-native species introduction (NBIC 2016). Two main tributaries of Presque Isle Bay, Mill Creek and Cascade Creek, account for two-thirds of the bay's water supply.

Methods

Adult and juvenile fish were targeted using diverse sampling gears deployed at a range of water depths in an attempt to collect as many species present as possible. An equal amount of sampling effort was deployed across gear types in order to discover which types collected a greater number of unique species.

Sampling gears used to target adult and juvenile fish included paired fyke nets, boat electrofishing, and juvenile seine nets. Paired fyke nets consisted of two 0.91 m x 1.22 m fyke nets constructed of 4.69 mm (3/16" delta) stretch mesh netting that were attached together with a

15 m x 0.91 m lead resulting in a paired net. Each individual net consisted of two rectangular frames 0.91 m x 1.22 m, followed by four circular rings 0.91 m in diameter. Paired fyke nets were set parallel to the shoreline or in "weed pockets" in water depths of 1.0-4.4 m. Nets were set during the day and remained in the water overnight for a period of 12-30 hours. Effort was measured in hours fished.

Boat electrofishing was conducted during the day in water depths of 1-3 m. A pulsed DC current 60 Hz electrical unit was used with sufficient power to induce taxis in fish. Electrofishing power was dependent upon water conductivity and the level of boat-hull oxidation. Electrofishing was conducted along one 600 s transect near each selected waypoint in water 1-3 m in depth. Effort was converted to hours fished.

The juvenile seine consisted of a 9 m x 1.5 m net with a 3 mm mesh size that excluded larvae while retaining juveniles, and a top float line with a weighted bottom line (lead line) that allowed for continuous surface to bottom contact minimizing net avoidance. Seining was conducted in shallow (< 2 m) littoral habitats with relatively navigable substrate for net operators. Sampling required two operators pulling the net through the entire water column (surface to bottom) from roughly a 1.5 m depth to the shore. Once at the shore, the float and lead line were dragged to shore while the netting remained in the water allowing for the fish collected to be housed in a live-well like fashion to then be sampled. Effort was deemed as the number of fish collected per the total number of seine net hauls.

Site selection was determined ad-hoc in the field by crew leaders with a focus on diversifying habitat and coverage of the bay.

All fish collected during sampling were identified to species. When a fish could not be identified in the field, it was preserved in 95% ethanol and brought back for identification in the lab. Tissue samples were taken on select fish whose identification was questionable, usually in addition to preserving the whole specimen for lab identification. Tissue samples were taken by clipping a small portion of a fin and preserving it in an individual 2 mL vial with 95% ethanol. Tissue samples are pending genetic barcoding analysis. All species of fish other than Round Goby *Neogobius melanostomus* were released unharmed, and gobies were euthanized in accordance with state regulations and the terms of scientific collection permits. Water quality data was collected at each site and included surface temperature (°C), secchi depth (m), dissolved oxygen (mg/l), and conductivity (µS/cm; at electrofishing sites). Catch per unit effort was determined for all species collected.

Results

A total of 24,259 fish representing 30 species were collected (Table A-1). Two species collected are currently listed as endangered by the Pennsylvania Fish and Boat Commission, the Spotted

Gar *Lepisosteus oculatus* and Warmouth *Lepomis gulosus*. A number of established non-native species were collected including Common Carp *Cyprinus carpio*, Goldfish *Carrasius auratus*, Round Goby, and White Perch *Morone americana*.

A total of 22,745 fish representing 23 species were collected as a result of eight paired fyke net sets (167.07 hours of effort) sampled between October 17 and 19, 2016 at surface water temperatures between 12.9 and 18.5℃. The most abundant species were Bluegill *Lepomis macrochirus* (89% of total catch), Yellow Perch *Perca flavescens*(9% of total catch), Rock Bass *Ambloplites rupestris* (1% of total catch), and Pumpkinseed *Lepomis gibbosus* (1% of total catch). Fyke nets caught five species unique to this gear including Brown Trout *Salmo trutta*, Northern Hog Sucker *Hypentelium nigricans*, White Bass *Morone chrysops*, White Crappie *Pomoxis annularis,* and White Perch.

A total of 1,106 fish representing 24 species were collected using 15 day electrofishing transects (2.5 hours of effort) sampled between October 17 and 19, 2016 at surface water temperatures between 17.4 and 20.5℃. The most abundant species encountered were Yellow Perch (40% of total catch), Bluegill (20% of total catch), Largemouth Bass *Micropterus salmoides* (12% of total catch), and Pumpkinseed (6% of total catch). Electrofishing caught five species unique to this gear including Bowfin *Amia calva*, Common Carp, Gizzard Shad *Dorosoma cepedianum*, Goldfish, and Smallmouth Bass *Micropterus dolomieu* .

A total of 408 fish representing 10 species were collected as a result of six juvenile seine net tows sampled on October 17, 2016 at surface temperatures between 17.1 and 21.6℃. The most abundant species were Brook Silverside *Labidesthes sicculus* (46% of total catch), Bluegill (31% of total catch), Banded Killifish *Fundulus diaphanus* (10% of total catch), Rock Bass (3% of total catch), and Round Goby (3% of total catch). None of the species caught were unique to juvenile seine nets.

Discussion

The 2016 pilot survey conducted in Presque Isle Bay evaluated a potential new study area for early detection monitoring, while determining the most effective gears to detect rare species at low abundance. A large number of fish species, both native and non-native were caught. No previously undocumented species were captured; however, two Pennsylvania State endangered fish, Spotted Gar and Warmouth, were captured using electrofishing and paired fyke nets. The Presque Isle pilot study demonstrated that electrofishing and fyke nets were the most effective gears at catching unique species. Data from this pilot study will aid in evaluating whether to add this location to future sampling plans and help in identifying priority gear types that are most effective for this area.

References

Great Lakes Water Quality Agreement. 1987. Protocol amending the agreement between Canada and The United States of America on Great Lakes water quality, 1978, as amended on October 16, 1983 and on November 18, 1987 and on September 7, 2012.

NBIC (National Ballast Information Clearinghouse). 2016. NBIC Online Database. Electronic publication, Smithsonian Environmental Research Center and United States Coast Guard. Available: http://invasions.si.edu/nbic/search.html. (March 2016).

TABLE A-1. Catch summary for juvenile and adult fish species collected from Presque Isle Bay during 2016.

Scientific name	Common name	Electrofishing (Day)		Paired Fyke Net		Juvenile Seine Net	Total
		Number collected	CPUE (fish/hr)*	Number collected	CPUE (fish/hr)*	Number collected	
Fundulus diaphanus	Banded Killifish	6	2.400	34	0.204	40	80
Pomoxis nigromaculatus	Black Crappie	2	0.800	18	0.108	0	20
Lepomis macrochirus	Bluegill	220	88.000	20,138	120.536	128	20,486
Pimephales notatus	Bluntnose Minnow	2	0.800	7	0.042	3	12
Amia calva	Bowfin	21	8.400	0	0.000	0	21
Labidesthes sicculus	Brook Silverside	8	3.200	0	0.000	189	197
Ameiurus nebulosus	Brown Bullhead	35	14.000	19	0.114	0	54
Salmo trutta	Brown Trout ^	0	0.000	1	0.006	0	1
Cyprinus carpio	Common Carp ^	14	5.600	0	0.000	0	14
Notropis atherinoides	Emerald Shiner	26	10.400	0	0.000	6	32
Dorosoma cepedianum	Gizzard Shad	51	20.400	0	0.000	0	51
Notemigonus crysoleucas	Golden Shiner	13	5.200	2	0.012	0	15
Carassius auratus	Goldfish ^	35	14.000	0	0.000	0	35
Micropterus salmoides	Largemouth Bass	132	52.800	65	0.389	0	197
Percina caprodes	Logperch	1	0.400	1	0.006	0	2
Hypentelium nigricans	Northern Hog Sucker	0	0.000	1	0.006	0	1
Esox lucius	Northern Pike	5	2.000	1	0.006	0	6
Lepomis gibbosus	Pumpkinseed	71	28.400	206	1.233	2	279
Ambloplites rupestris	Rock Bass	7	2.800	211	1.263	14	232
Neogobius melanostoma	Round Goby ^	6	2.400	53	0.317	13	72
Micropterus dolomieu	Smallmouth Bass	4	1.600	0	0.000	0	4
Notropis hudsonius	Spottail Shiner	0	0.000	6	0.036	6	12
Lepisosteus oculatus	Spotted Gar	1	0.400	2	0.012	0	3
Lepomis gulosus	Warmouth	2	0.800	2	0.012	0	4
Morone chrysops	White Bass	0	0.000	1	0.006	0	1
Pomoxis annularis	White Crappie	0	0.000	11	0.066	0	11
Morone americana	White Perch ^	0	0.000	22	0.132	0	22
Catostomus commersonii	White Sucker	4	1.600	2	0.012	0	6
Ameiurus natalis	Yellow Bullhead	3	1.200	7	0.042	0	10
Perca flavescens	Yellow Perch	437	174.800	1935	11.582	7	2379
	Total	1,106		22,745		408	24,259

* Sampling effort for electrofishing was 2.5 hours, paired fyke nets was 167.07 hours.

^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

FIGURE A-1. Presque Isle Bay showing locations sampled for juvenile and adult fish during 2016.

Appendix B – Ichthyoplankton Collection Methodology Pilot Study

Introduction

Recent challenges with ichthyoplankton collection in the Buffalo/upper Niagara River have led to consideration of alternative sampling methods to increase larval fish collection. Currently, ichthyoplankton is collected via nighttime surface circle tows with paired bongo nets and light trap sets. Although these sampling methods collect larval fish in the Buffalo/upper Niagara River, catches appear to be an under representation of the ichthyoplankton community. Therefore, an experimental study was implemented to determine if different sampling methods and gears increased ichthyoplankton catch rates and species richness in the Buffalo/upper Niagara River sampling area. The results from this study will guide future U. S. Fish and Wildlife Service (USFWS) early detection and monitoring sampling for aquatic invasive species as it pertains to ichthyoplankton collections.

Methods

Sampling occurred at random sites within the Buffalo/upper Niagara River area in Lake Erie (Figure B-1). Paired bongo nets (500 micron mesh, 0.5 m diameter) were used to sample during nighttime hours (20:00-03:00). Two methods of bongo net sampling were conducted and compared, circle (surface) and transect (depth integrated straight line) tows. Circle tows (n = 5) were five minutes in duration and with the net frame just below the surface of the water. Sampling was conducted adjacent (e.g. port or starboard side) to the sampling vessel to avoid prop wash. Transect tows (n = 5) were of variable depth (i.e. towing began at the surface and then the net was lowered and raised through the water column) with a duration of 10 minutes per tow. Upon tow lift, the net contents were washed down into net sample buckets, then transferred to 500 ml plastic sample bottles and preserved with 95% ethanol. Both circle and transect tows were conducted on the same night, from the same vessel, and at the same location to standardize the comparisons. Ichthyoplankton catches, excluding eggs, from the same date and site were used to compare the sampling methods.

Similar to the bongo net tow comparisons, the efficiency of nighttime light traps was also tested. Light traps (n = 9) were quatrefoil in style (0.3 m diameter, 0.25 m long, gap width 5 mm, 500 micron mesh) and were anchored in waters less than 1 m in depth, and fished at night from one hour past sunset for six to eight hours. Traps were recovered and the contents were washed down into a mesh bag at the bottom of the trap. Seining (n = 8) was conducted using a 2.5 x 1.1 m 500 micron mesh larval seine net during the daytime hours (09:00-16:00) in similar habitats to which light traps were set. This included shallow, near shore habitats which were typically vegetated. Larval seining was conducted with two operators pulling the net from roughly a 1.5 m depth to the shore. Only one seine haul was conducted at each site. Both light trap sets and larval seine hauls were conducted in the Buffalo/upper Niagara River area.

All fish collected in ichthyoplankton sampling gears were preserved in 95% ethanol in the field and then identified in the lab. For bongo nets, only specimens collected in the port side net were identified and included in the study. All specimens, excluding eggs, were identified to the lowest possible taxa using Auer's (1982) key to larval fishes of the Great Lakes. All identified specimens will be sent to the USFWS Lamar Fish Health Laboratory in Lamar, Pennsylvania for genetic barcoding.

Analysis

Ichthyoplankton data was analyzed predominantly for catch per unit effort (CPUE). The CPUE by gear was measured in fish/10 m^3 for bongo nets, fish/hour for light traps, and fish/net haul for larval seines, and the information is provided in catch summary tables. Biotic data for this study includes the lowest possible taxonomic identification for each specimen collected, along with the total number of specimens collected at each site for each gear/method. Two-sample t-tests were conducted to determine whether the mean catches were different amongst gears/methods (light trap vs. larval seine and circle vs. transect bongo net tows). F-tests were conducted to assess homogeneity of variance for each t-test and those results informed the appropriate type of t-test used (equal or unequal variances). Statistical tests were conducted using Microsoft Excel's data analysis tool.

Results

The mean CPUE of transect bongo net tows (mean = 5 fish/10 m^3; SE = 1.28) was higher than that of circle bongo net tows (mean = 2.6 fish/10 m^3; SE = 1.44). However, this finding was not significant (t = -1.04, df = 8, $P > 0.05$, Figure B-2). When comparing catches from a species richness perspective, transect tows captured six species and one unique taxa while circle tows collected only three species (Figure B-2). Round Goby *Neogobius melanostomus* (0.12 fish/10 m^3) and White Perch *Morone americana* (0.06 fish/10 m^3), two non-native species, were the most commonly captured species in the transect tows while White Perch (0.15 fish/10 m^3) and Yellow Perch *Perca flavescens* (0.12 fish/10 m^3) were captured most predominantly in the circle tows (Table B-1).

The mean CPUE of larval seines (mean = 381.8 fish/haul, SE = 211.1) was higher than that of nighttime light trap sets (mean = 9.2 fish/h, SE = 4.25). However, the difference was not significant (t = 1.76, df = 7, P = 0.06, Figure B-3). Larval seines collected 15 species and one unique taxa while nighttime light trap sets collected six species (Figure B-3). The most common species collected in larval seines were Spottail Shiners *Notropis hudsonius* (182.6 fish/haul), Redhorse sp. (107.6 fish/haul), and Catostomidae sp. (85.5 fish/haul); while Round Goby (0.85 fish/hour) and Bluegill *Lepomis macrochirus* (0.37 fish/hour) were the predominant catch in nighttime light trap sets (Table B-2). Overall, larval seines appeared to collect both a larger number of individuals and species. However, those differences were not statistically significant.

Discussion

This pilot study aimed to determine more efficient methods to collect ichthyoplankton in the Buffalo/upper Niagara River area as it pertains to early detection and monitoring of larval invasive fish species. Past program catch rates and species richness of surface bongo net tows and light trap sets appeared to underrepresent the ichthyoplankton community of this area. Historic seasonal catches (2014: 189, 2015: 108, 2016: 219) of larval fish at this eastern Lake Erie basin sampling site has been drastically lower than sampling locations in the western basin of Lake Erie (see results for Maumee Bay and Sandusky Bay in main report). Notable differences were discovered for ichthyoplankton species richness between the sampling gears and methods used during this study and those used for current early detection and monitoring of ichthyoplankton by the USFWS across Lake Erie. (Notable, though not statistically significant differences - particularly with regard to species richness -were found when comparing the performance of gear types and deployment methods. These results will inform the gear and methodology choices in future sampling efforts for the USFWS early detection monitoring program.)

Nighttime surface bongo net tows are a common practice in ichthyoplankton sampling (Claramunt et al. 2005, McCullough et al. 2015). This is an especially effective method when targeting larval fish that have a diel vertical migration tendency, such as the Round Goby (Hensler and Jude 2007). However, when attempting to collect the largest possible number of ichthyoplankton species, surface bongo net tows may miss a portion of the ichthyoplankton community within Lake Erie. Depth integrated bongo net tows (transects), when compared to surface circle tows, appeared to obtain a better representation of the ichthyoplankton community via its increased species richness (Figure B-2, Table B-1). However, due to the increased effort of these tows (transects filtered 997.51 m^3 in a 10 minute tow duration, circles filtered 399.79 m^3 in a 5 minute tow duration) it is inconclusive to state that transects were a better ichthyoplankton sampling method than surface circle tows with such a discrepancy. Therefore, further evaluation, such as even sampling effort and a larger sample size, is needed for a conclusive comparison.

Light traps are one of the most popular ichthyoplankton collection methods. However, light traps tend to favor larvae which are photopositive, thus potentially biasing ichthyoplankton catches (Thorrold 1992). If the intention is to collect diverse taxa, both Choat et al. (1993) and Hickford and Schiel (1999) suggested that when compared to active gears such as nets, light traps contributed either no or minimal additional taxa to the overall ichthyoplankton catch. However, other studies have suggested that taxonomic composition of larval fish between light traps and active sampling gears are relatively similar or superior (Brogan 1994, Niles and Hartman 2007). The current pilot study found that larval seining, an active sampling ichthyoplankton gear, collected more individuals and greater species richness than that of light traps (Figure B-3, Table B-2). Larval seining also collected a high number of low abundance species (Table B-2), a crucial requirement when sampling for invasive species which are often in low abundances when

first introduced to new locations (Hoffman et al. 2016). These findings warrant further investigation to determine if larval seines or other near shore active ichthyoplankton sampling gear are more efficient (abundances and species richness) than light traps when sampling the same habitats.

Ichthyoplankton sampling is a relatively new tool used by the USFWS for early detection and monitoring of invasive species in the Great Lakes basin. Therefore, further experimentation on gear efficiency is required, especially when low catch rates are observed. Methods such as integrated depth bongo net transect tows and larval seining show promise in helping achieve increased detections of ichthyoplankton species within the eastern basin of Lake Erie. However, these are only a few proposed alternatives. Other gears, such as push nets, should also be considered to increase abundance and species richness in order to accurately sample the larval fish community.

References

Auer, N. A. 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Special Publication 82-3. Great Lakes Fishery Commission, Ann Arbor, Michigan.

Brogan, M. W. 1994. Two methods of sampling fish larvae over reefs: a comparison from the Gulf of California. Marine Biology 118(1):33-44.

Choat, J. H., J. P. Doherty, B. A. Kerrigan, and J. M. Leis. 1993. A comparison of towed nets, purse seine, and light-aggregation devices for sampling larvae and pelagic juveniles of coral-reef fishes. Fishery Bulletin 91(2):195-209.

Claramunt, R.M., D. E. Shoup, and D. H. Wahl. 2005. Comparison of push nets and tow nets for sampling larval fish with implications for assessing littoral habitat utilization. North American Journal of Fisheries Management 25(1):86-92.

Hensler, S. R., and D. J. Jude. 2007. Diel vertical migration of round goby larvae in the Great Lakes. Journal of Great Lakes Research 33(2):295-302.

Hickford, M. J., and D. R. Schiel. 1999. Evaluation of the performance of light traps for sampling fish larvae in inshore temperate waters. Marine Ecology Progress Series 186:293-302.

Hoffman, J. C., J. Schloesser, A. S. Trebitz, G. S. Peterson, M. Gutsch, H. Quinlan, and J. R. Kelly. 2016. Sampling design for early detection of aquatic invasive species in Great Lakes Ports. Fisheries 41(1):26-37.

McCullough, D. E., E. F. Roseman, K. M. Keeler, R. L. DeBruyne, J. J. Pritt, P. A. Thompson, S. Ireland, J. E. Ross, D. Bowser, R. D. Hunter, and D. Castle. 2015. Evidence of the St. Clair-Detroit River system as a dispersal corridor and nursery habitat for transient larval Burbot. Hydrobiologia 757(1):21-34.

Niles, J. M., and K. J. Hartman. 2007. Comparison of three larval fish gears to sample shallow water sites on a navigable river. North American Journal of Fisheries Management 27(4):1126-1138.

Thorrold, S. R. 1992. Evaluating the performance of light traps for sampling small fish and squid in open waters of the central Great Barrier Reef lagoon. Marine ecology progress series. Oldendorf 89(2):277-285.

TABLE B-1. Summary of ichthyoplankton species collected from Buffalo/upper Niagara River with nighttime circle and transect bongo net tows during 2016.

		Bongo Nets				
		Circle Tow		Transect Tow		
Scientific Name	Common Name	Number Collected	CPUE (fish/10 m^3)*	Number Collected	CPUE (fish/10 m^3)*	Total
Alosa pseudoharengus	Alewife^	0	0.000	1	0.010	1
Lepomis sp.	Lepomis sp.	0	0.000	1	0.010	1
Notropis atherinoides	Emerald Shiner	0	0.000	2	0.020	2
Neogobius melanostoma	Round Goby^	0	0.000	12	0.120	12
Osmerus mordax	Rainbow Smelt^	0	0.000	1	0.010	1
Micropterus dolomiue	Smallmouth Bass	0	0.000	1	0.010	1
Morone chrysops	White Bass	2	0.050	0	0.000	2
Morone sp.	White Bass/White Perch^	0	0.000	1	0.010	1
Morone americana	White Perch^	6	0.150	6	0.060	12
Perca flavescens	Yellow Perch	5	0.125	0	0.000	5
	Total	13		25		38

* Sampling effort for circle bongo net tows was 399.79 m^3 and transect bongo net tows was 997.51 m^3.

^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

TABLE B-2. Summary of ichthyoplankton species collected from Buffalo/upper Niagara River with larval seine net hauls and nighttime light trap sets during 2016.

		Larval Seine		Light Trap		
Scientific Name	Common Name	Number Collected	CPUE (fish/net haul)*	Number Collected	CPUE (fish/hour)*	Total
Notropis heterodon	Blackchin Shiner[1]	1	0.125	0	0.000	1
Notropis heterolepis	Blacknose shiner	1	0.125	0	0.000	1
Lepomis macrochirus	Bluegill	0	0.000	20	0.369	20
Pimephales notatus	Bluntnose Minnow	2	0.250	0	0.000	2
Labidesthes sicculus	Brook Silverside	3	0.375	0	0.000	3
Luxilus cornutus	Common Shiner	5	0.625	0	0.000	5
Notropis atherinoides	Emerald Shiner[1]	4	0.500	0	0.000	4
Pimephales promelas	Fathead Minnow	10	1.250	0	0.000	10
Dorsoma cepedianum	Gizzard Shad	0	0.000	3	0.055	3
Notemigonus crysoleucas	Golden Shiner	2	0.250	0	0.000	2
Micropterus salmoides	Largemouth Bass	2	0.250	4	0.074	6
Lepomis gibbosus	Pumpkinseed	0	0.000	8	0.148	8
Carpiodes cyprinus	Quillback	1	0.125	0	0.000	1
Moxastoma sp.	Redhorse sp.	861	107.625	0	0.000	861
Neogobius melanostoma	Round Goby^	0	0.000	46	0.849	46
Micropterus dolomieu	Smallmouth Bass	8	1.000	0	0.000	8
Notropis hudsonius	Spottail Shiner	1,461	182.625	0	0.000	1,461
Luxilus chryocephalus	Striped Shiner	1	0.125	0	0.000	1
Catostomidae sp.	Sucker sp.	684	85.500	0	0.000	684
Pomoxis annularis	White Crappie	0	0.000	2	0.037	2
Catostomus commersonii	White Sucker	4	0.500	0	0.000	4
Perca flavescens	Yellow Perch	6	0.750	0	0.000	6
	Total	3,056		83		3,139

* Sampling effort for larval seine net hauls was 8 and nighttime light trapping was 54.15 hours.

^ Species not native to the Lake Erie watershed according to the Great Lakes Aquatic Nonindigenous Species Information System (USGS 2017).

[1] Adults also collected.

FIGURE B-1. Buffalo and the upper Niagara River showing locations sampled for the ichthyoplankton pilot study.

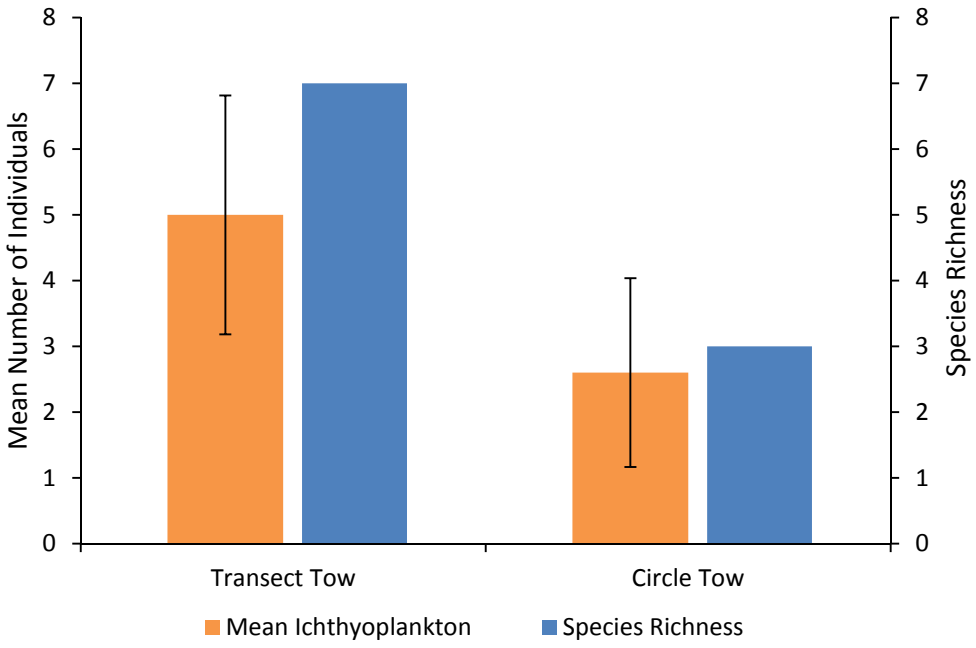


FIGURE B-2. Mean number of individuals collected per sample (orange bars, left y-axis) along with species richness (blue bars, right y-axis) of nighttime transect (n = 5) and circle (n = 5) bongo net tows in the Buffalo/upper Niagara River sampling area. Bars represent standard error.

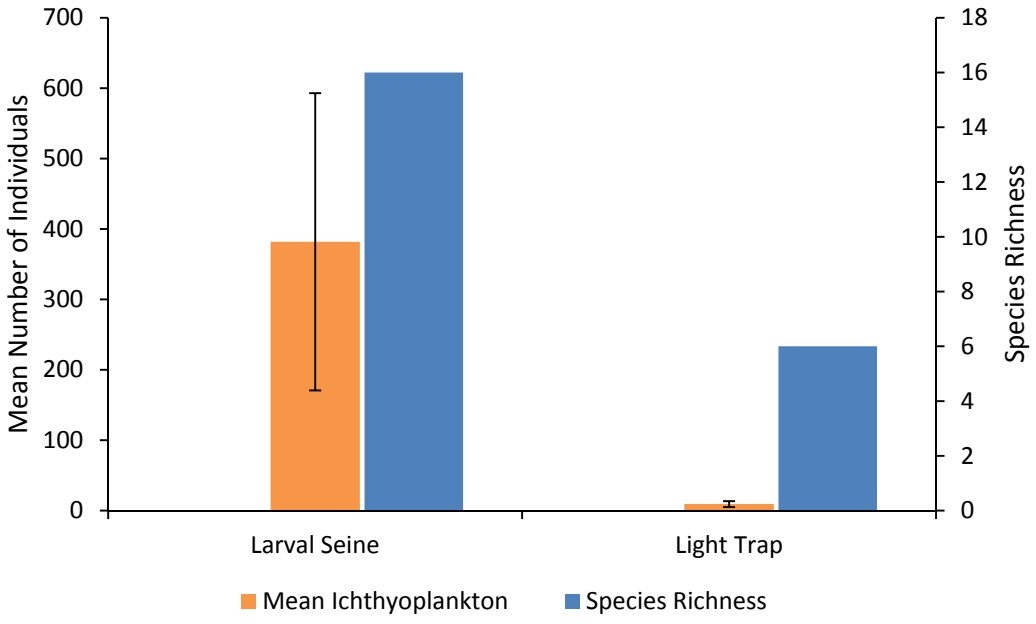


FIGURE B-3. Mean number of individuals collected per sample (orange bars, left y-axis) along with species richness (blue bars, right y-axis) of light trap sets (n = 9) and larval seine hauls (n = 8) in the Buffalo/upper Niagara River sampling area. Bars represent standard error.

Appendix C - Exploring Methods to Increase Detection Efficiency

Introduction

After four years of sampling at four locations within the Lake Erie basin (Detroit River, Maumee Bay, Sandusky Bay, and Buffalo/upper Niagara River), the goal of 95% detection efficiency has only been met at the Detroit River during the fourth year. Here we explore two methods to increase detection efficiency and the capture of unique species: 1) are multiple sampling gears sampling the same fish community, allowing for one gear to be eliminated and replaced; 2) are there areas within each sampling region that contain "hot spots" or areas with high species richness that can be targeted to aid in rapid species detection. The ability to reach 95% detection efficiency more rapidly will aid in early detection of newly introduced species, while they are still in low abundance.

Methods

Assessing Fish Communities Sampled

Nonmetric multidimensional scaling (NMDS) was used to assess the similarity of fish communities sampled by each sampling gear. Presence/absence data was used for each gear type. Rare species were included in the analysis since capturing rare species is important for early detection monitoring programs. Low stress values and Monte Carlo randomization tests (n=250 runs) were used to determine the number of required axes for the NMDS (McCune and Grace 2002). Ordinations resulting in stress values less than 20 were considered satisfactory (McCune and Grace 2002). NMDS was performed in PC-ORD version 5.

Multi-response permutation procedure (MRPP) with Sorensen (Bray-Curtis) distances was used to determine significant (α=0.05) differences among gear types. MRPP provides a *p*-value that estimates the probability that the observed differences are due to chance and an agreement statistic (*A*) that describes within-group homogeneity compared to that expected by chance (McCune and Grace 2002). *A* values range from less than zero to one with an *A* of zero indicating a level of heterogeneity expected by chance and an *A* of one indicating that all items within groups are identical. *A* values are typically below 0.1 in community ecology and values above 0.3 are considered fairly high (McCune and Grace 2002). MRPP was performed in PC-ORD version 5.

Hot Spot Analysis

The Hot Spot Analysis (Getis-Ord Gi*) tool within ArcGIS 10.4 was used to statistically identify species richness clusters in all AIS sampling locations for data from 2013 to 2016 (Ord and Getis 1995). The Getis-Ord Gi* statistic provides z-scores and *p* values that identify the significance of clustering at a given distance (Ord and Getis 1995). Z-scores greater than 1.96 or below -1.96 indicate statically significant hot or cold spots with *p* values ≤ 0.05. A high z-score indicates that

the features have a cluster of similar high values, while a low z-score indicates that the features have a cluster of similar low values.

The Global Moran's I (spatial autocorrelation) tool within the spatial statistics toolbox in ArcGIS 10.4 was used to evaluate the presence of significant ($p \leq 0.05$) spatial clustering between the sampling locations (Jalali et al. 2015; Sanchez-Cuervo and Aide 2013). When the species richness sampling locations exhibited spatial clustering, the next step was to objectively identify the proper distance band threshold (i.e., search radius) for the hotspot analysis using the incremental spatial autocorrelation analysis within the spatial statistics toolbox (Jalali et al. 2015). This threshold is the first significant peak from the incremental spatial autocorrelation output report and represents a distance where spatial clustering is pronounced. For example, the first peak was 2547.81 m or 1.58 miles for Maumee Bay trawling sites. Settings for the tools included Euclidean distance for Moran's I, incremental spatial autocorrelation and the hot spot analysis, while the zone of indifference was used for Moran's I and the hot spot analysis. Moran's I was run for each bay by gear type. When the Moran's I output indicated clustering the incremental spatial autocorrelation and hot spot analyses were run for each bay by gear type.

Results

Assessing Fish Communities Sampled

Detroit River—NMDS ordination for the Detroit River was best fit on two axes and had a final stress value of 21.70 (Figure C-1). According to "Clarkes rules of thumb", stress values above 20 yield plots that are relatively dangerous to interpret (McCune and Grace 2002). However, MRPP showed fish communities sampled differed among all gear types (MRPP: A=0.36, p<0.001). For pairwise comparisons, fish communities sampled differed between electrofishing and paired fyke nets (MRPP: A=0.22, p<0.001), electrofishing and minnow traps (MRPP: A=0.29, p<0.001), and paired fyke nets and minnow traps (MRPP: A=0.30, p<0.001).

Maumee Bay— NMDS ordination for Maumee Bay was best fit on three axes and had a final stress value of 18.67 (Figure C-2). According to "Clarkes rules of thumb", stress values of this sort can correspond to a usable picture, but have the potential to mislead (McCune and Grace 2002). MRPP showed fish communities sampled differed among all gear types (MRPP: A=0.26, p<0.001). For pairwise comparisons, fish communities sampled differed between electrofishing and paired fyke nets (MRPP: A=0.27, p<0.001), electrofishing and bottom trawling (MRPP: A=0.23, p<0.001), and paired fyke nets and bottom trawling (MRPP: A=0.14, p<0.001).

Sandusky Bay—NMDS ordination for Sandusky Bay was best fit on three axes and had a final stress value of 16.45 (Figure C-3). According to "Clarkes rules of thumb", stress values of this sort can correspond to a usable picture, but have the potential to mislead (McCune and Grace 2002). MRPP showed fish communities sampled differed among all gear types (MRPP: A=0.32, p<0.001). For pairwise comparisons, fish communities sampled differed between electrofishing

and paired fyke nets (MRPP: A=0.32, p<0.001), electrofishing and bottom trawling (MRPP: A=0.19, p<0.001), and paired fyke nets and bottom trawling (MRPP: A=0.24, p<0.001).

Buffalo and Upper Niagara River—NMDS ordination for Buffalo and upper Niagara River was best fit on three axes and had a final stress value of 18.40 (Figure C-4). According to "Clarkes rules of thumb", stress values of this sort can correspond to a usable picture, but have the potential to mislead (McCune and Grace 2002). MRPP showed fish communities sampled differed among all gear types (MRPP: A=0.18, p<0.001). For pairwise comparisons, fish communities sampled differed between electrofishing and paired fyke nets (MRPP: A=0.06, p<0.001), electrofishing and bottom trawling (MRPP: A=0.16, p<0.001), and paired fyke nets and bottom trawling (MRPP: A=0.32, p<0.001).

Hotspot Analysis

Detroit River

Electrofishing—From 2013 to 2016 a total of 31 electrofishing sites were sampled in the Detroit River, Michigan and Ontario. These results should be interpreted with caution because the number of sites sampled is near the recommended minimum number of 30 for conducting a hot spot analysis. The number of species caught at a given sampling location ranged from 0 to 15 with a mean of 6.54 species (SD = 4.14). The Global Moran's I statistic indicated that the species richness sites are not significantly clustered (p = 0.69). Therefore, no significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$; Figure C-5).

Paired Fyke Net—From 2013 to 2016 a total of 58 paired fyke net sites were sampled in the Detroit River, Michigan and Ontario. The number of species caught at a given sampling location ranged from 3 to 21 with a mean of 10.64 species (SD = 3.80). The Global Moran's I statistic indicated clustering among species richness sampling locations, but not significantly (p = 0.08). The first peak from the Global Moran's I was 6975.71 m (4.33 miles) and was used as an input for the hot spot analysis. A total of seven significant hot spot sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$). The sites with high species richness are clustered in the middle of the Detroit River near Fighting Island (Figure C-6).

Minnow Traps—From 2013 to 2016 a total of 45 minnow trap sites were sampled in the Detroit River, Michigan and Ontario. The number of species caught at a given sampling location ranged from 1 to 4 with a mean of 2.53 species (SD = 1.14). The Global Moran's I statistic indicated clustering among species richness sampling locations, but not significantly (p = 0.09). The first peak from the Global Moran's I was 4787.23 m (2.97 miles) and was used as an input for the hot spot analysis. A total of eight significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$). One significant cold spot was identified at the southernmost Detroit River site, and

seven significant hot spots were identified in the lower-middle portion of the Detroit River near the island of Grosse Ile (Figure C-7).

Maumee Bay

Electrofishing—From 2013 to 2016 a total of 24 electrofishing sites were sampled in Maumee Bay, Ohio. These results should be interpreted with caution because the number of sites sampled is lower than the recommend number of 30 or more for conducting a hot spot analysis. The number of species caught at a given sampling location ranged from 0 to 17 with a mean of 4.17 species (SD = 4.24). The Global Moran's I statistic indicated clustering among species richness locations, but not significantly ($p < 0.08$). The first peak from the Global Moran's I was 3490.55 m (2.17 miles) and was used as an input for the hot spot analysis. One significant hot spot site was identified with the Getis-Ord Gi* statistic ($p = 0.01$), and is located in the northwestern portion of the bay (Figure C-8).

Paired Fyke Nets—From 2013 to 2016 a total of 60 paired fyke net sites were sampled in Maumee Bay, Ohio. The number of species caught at a given sampling location ranged from 4 to 25 with a mean of 10.2 species (SD = 4.02). The Global Moran's I statistic indicated significant clustering among species richness sampling locations ($p = 0.02$). The first peak from the Global Moran's I was 1627.78 m (1.01 miles) and was used as an input for the hot spot analysis. Seven significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$). There are two significant cold spots (clustered low species richness) and five significant hot spots (clustered high species richness). The sites with high species richness are clustered nearshore in the northwestern portion of the bay, while the cold spots are clustered offshore (Figure C-9).

Trawling—For the years 2013, 2015, and 2016 a total of 45 bottom trawl sites were sampled in Maumee Bay, Ohio. Data from 2014, were removed from this analysis, because sampling took place much later in the year and may have influenced the number of fish captured. The number of species caught at a given sampling location ranged from 3 to 11 with a mean of 7.42 species (SD = 1.69). The Global Moran's I statistic indicated significant clustering among species richness sampling locations ($p < 0.01$). The first peak from the Global Moran's I was 2547.81 m (1.58 miles) and was used as an input for the hot spot analysis. A total of 27 significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$). There are 21 significant cold spots and six significant hot spots. Sites with high species richness are clustered in the southeastern portion of the bay, while the cold spots are clustered in the northern portion of the bay (Figure C-10).

Sandusky Bay

Electrofishing—From 2013 to 2016 a total of 45 electrofishing sites were sampled in Sandusky Bay, Ohio. The number of species caught at a given sampling location ranged from 0 to 10 with a mean of 3.87 species (SD = 2.67). The Global Moran's I statistic showed no evidence of

significant clustering among species richness sampling locations ($p = 0.48$). Therefore, no significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$; Figure C-11).

Paired Fyke Nets—From 2013 to 2016 a total of 48 paired fyke net sites were sampled in Sandusky Bay, Ohio. The number of species caught at a given sampling location ranged from 3 to 14 with a mean of 9.06 species (SD = 2.70). The Global Moran's I statistic indicated significant clustering among species richness sampling locations ($p = 0.02$). The first peak from the Global Moran's I was 2918.08 m (1.81 miles) and was used as an input for the hot spot analysis. A total of eight significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$). There are five significant cold spots (clustered low species richness) and three significant hot spots (clustered high species richness). The sites with high species richness are clustered in the western portion of the bay near the mouth of the Sandusky River, while the cold spots are clustered in the eastern portion of the bay (Figure C-12).

Trawling—From 2013 to 2016 a total of 60 bottom trawl sites were sampled in Sandusky Bay, Ohio. The number of species caught at a given sampling location ranged from 2 to 13 with a mean of 6.37 species (SD = 2.80). The Global Moran's I statistic indicated significant clustering among species richness sampling locations ($p < 0.01$). The first peak from the Global Moran's I was 2645.25 m (1.64 miles) and was used as an input for the hot spot analysis. A total of 23 significant sites were identified with the Getis-Ord Gi* ($p \leq 0.05$). The 23 significant sites are all cold spots or clusters of low species richness (Figure C-13).

Upper Niagara River/Buffalo

Electrofishing—From 2013 to 2016 a total of 132 electrofishing sites (day and night) were sampled in the Niagara River/Buffalo area, New York and Ontario. The number of species caught at a given sampling location ranged from 1 to 22 with a mean of 9.16 species (SD = 4.84). The Global Moran's I statistic indicated significant clustering among species richness sampling locations ($p < 0.01$). The first peak from the Global Moran's I was 2874.98 m (1.79 miles) and was used as the input for the distance threshold for the hot spot analysis. A total of 57 significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$). There are 22 significant cold spots (clustered low species richness) and 35 significant hot spots (clustered high species richness). Sites with high species richness are clustered near the upstream and downstream portions of Grand Island in the Niagara River, while cold spots are clustered at the southernmost sampling locations near Buffalo (Figure C-14).

Fyke Nets—From 2013 to 2016 a total of 32 paired fyke net sites were sampled in the Niagara River/Buffalo area, New York and Ontario. The number of species caught at a given sampling location ranged from 3 to 20 with a mean of 11.72 species (SD = 4.35). The Global Moran's I statistic indicated significant clustering among species richness sampling locations ($p < 0.01$). The first peak from the Global Moran's I was 7258.80 m (4.51 miles) and was used as the input

for the distance threshold for the hot spot analysis. A total of 15 significant sites were identified with the Getis-Ord Gi* statistic ($p \leq 0.05$). There are nine significant cold spots (clustered low species richness) and six significant hot spots (clustered high species richness). The sites with high species richness are clustered near the southern end of Grand Island in the Niagara River, while the cold spots are clustered in the bay near Buffalo (Figure C-15).

Trawling—Insufficient number of sampling points to run the hot spot analysis ($n = 17$).

Discussion

All sampling gears used captured unique fish communities at each location and thus provide value to our sampling regime. Even though NMDS ordinations provided results that were either dangerous to interpret or had the possibility of misleading (McCune and Grace 2002), MRPP found that fish communities captured by each gear type were unique. Therefore, none of our gear types currently used should be replaced on the basis that they capture similar fish communities.

The Hot Spot Analysis allowed us to spatially explore areas of high and low species richness. Species richness hot and cold spots varied by gear between the various sampling locations. Although, this method was limited to gear types with a sufficient number of sampling locations ($n \geq 30$). The results from this analysis will be used to increase species detection efficiency by targeting species richness hot spots. In 2017, a pilot study will be conducted in Maumee Bay to determine if the addition of targeted sampling in species richness hot spots with disproportionately more gear can increase species detection efficiency and/or lead to collecting a greater number of rare species.

References

Jalali, M. A., D. Ierodiaconou, H. Gorfine, J. Monk, and A. Rattray. 2015. Exploring spatiotemporal trends in commercial fishing effort of an abalone fishing zone: a GIS-based hotspot model. PloS one 10(5):e0122995.

McCune, B., and J. B. Grace. 2002. Analysis of Ecological Communities. MjM Software Design, Glenden Beach, Oregon.

Ord J. K., and A. Getis. 1995. Local Spatial Autocorrelation Statistics: Distributional Issues and an Application. Geographical Analysis 27:286–306.

Sanchez-Cuervo, A. M., and T. M. Aide. 2013. Identifying hotspots of deforestation and reforestation in Colombia (2001–2010): implications for protected areas. Ecosphere 4(11):1-21.

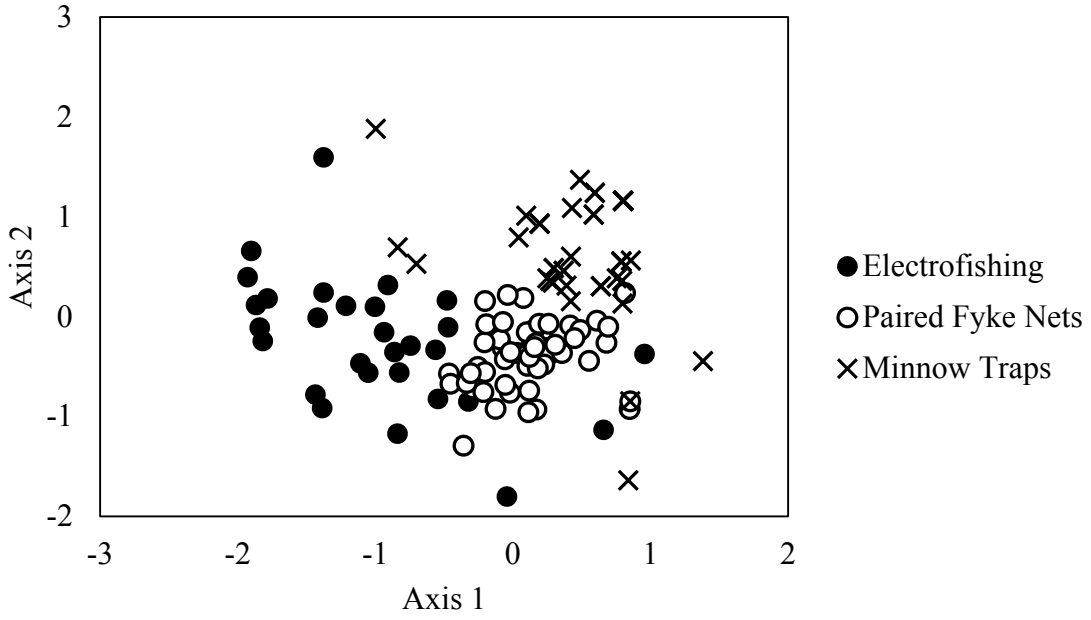


FIGURE C-1. Nonmetric Multidimensional Scaling (NMDS) plot comparing the fish community sampled in the Detroit River using multiple gear types from 2013-2016.

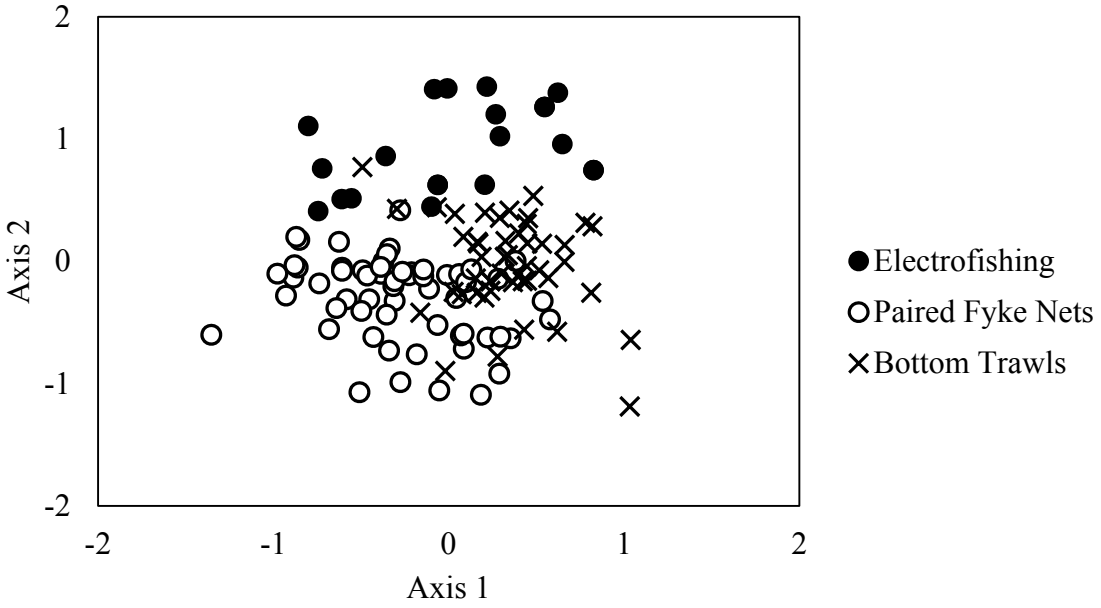


FIGURE C-2. Nonmetric Multidimensional Scaling (NMDS) plot comparing the fish community sampled in Maumee Bay using multiple gear types from 2013-2016.

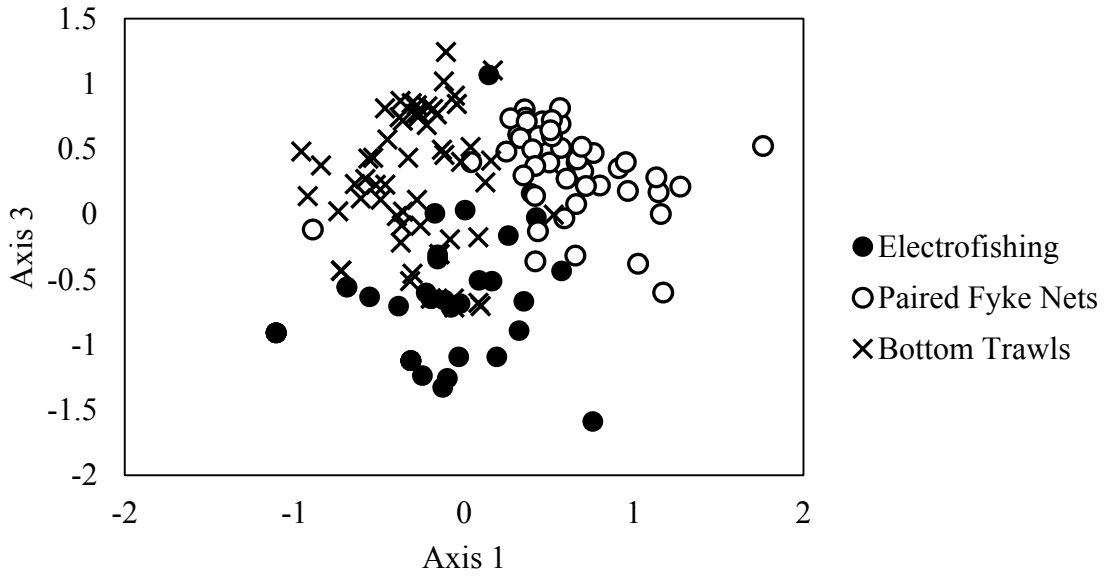


FIGURE C-3. Nonmetric Multidimensional Scaling (NMDS) plot comparing the fish community sampled in Sandusky Bay using multiple gear types from 2013-2016.

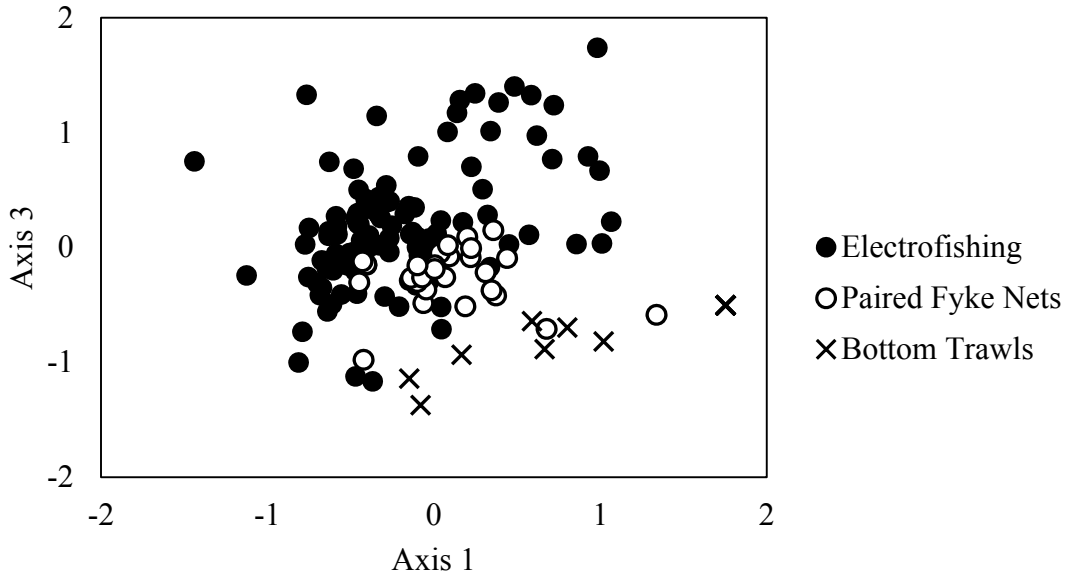


FIGURE C-4. Nonmetric Multidimensional Scaling (NMDS) plot comparing the fish community sampled in Buffalo and the Niagara River using multiple gear types from 2013-2016.

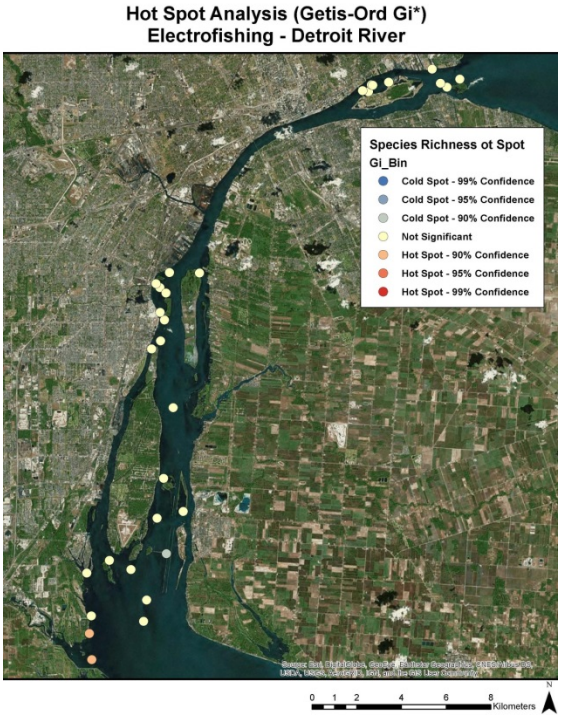


FIGURE C-5. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Detroit River electrofishing using data collected from 2013-2016.

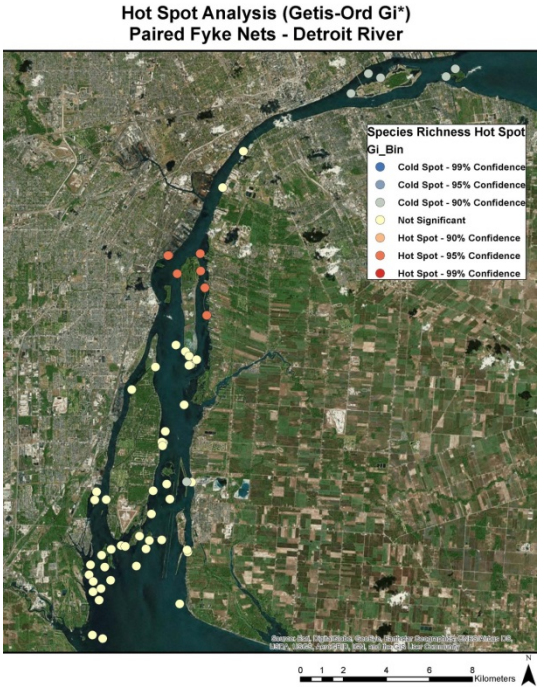


FIGURE C-6. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Detroit River paired fyke nets using data collected from 2013-2016.

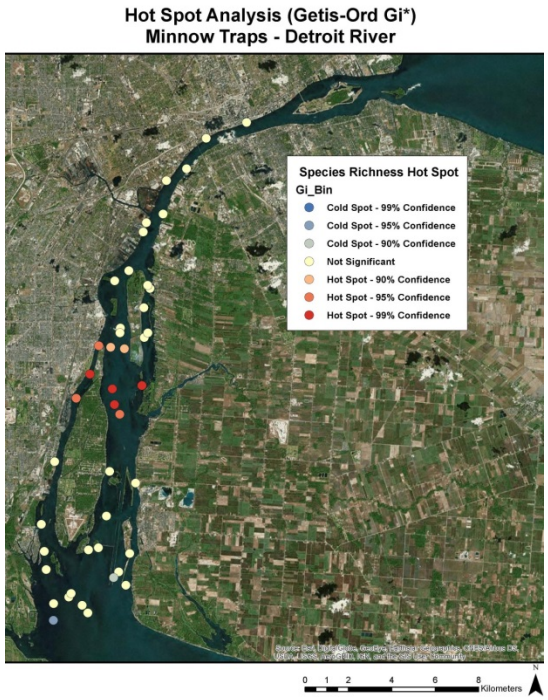


FIGURE C-7. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Detroit River minnow traps using data collected from 2013-2016.

FIGURE C-8. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Maumee Bay electrofishing using data collected from 2013-2016.

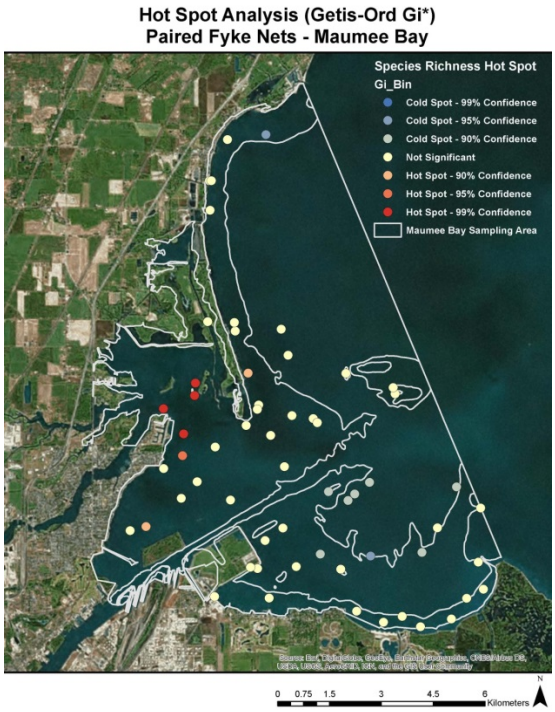


FIGURE C-9. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Maumee Bay paired fyke nets using data collected from 2013-2016.

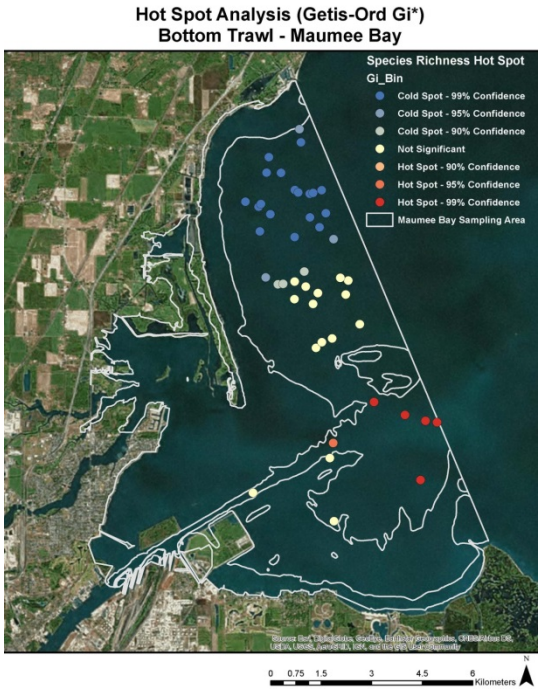


FIGURE C-10. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Maumee Bay bottom trawls using data collected from 2013-2016.

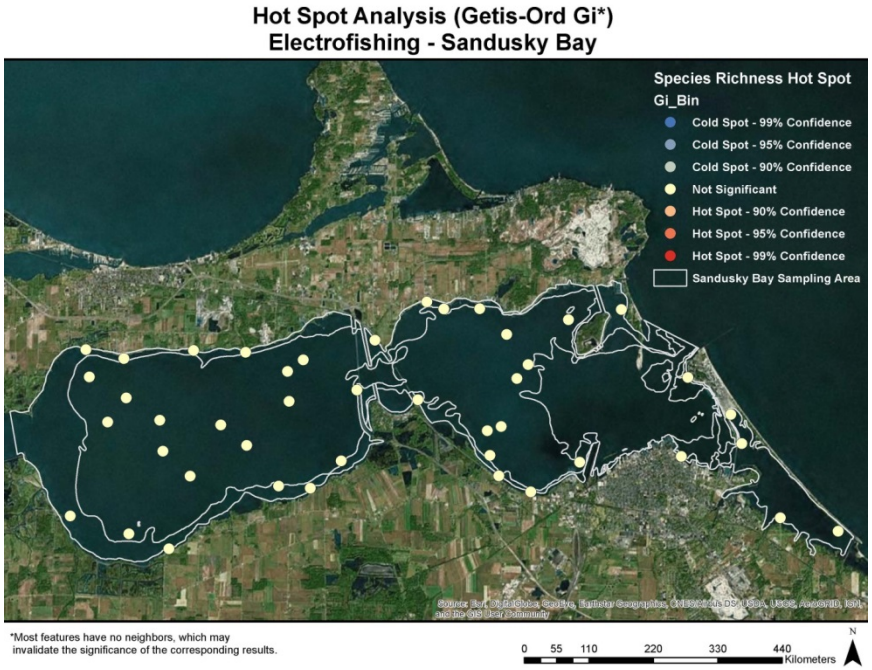


FIGURE C-11. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Sandusky Bay electrofishing using data collected from 2013-2016.

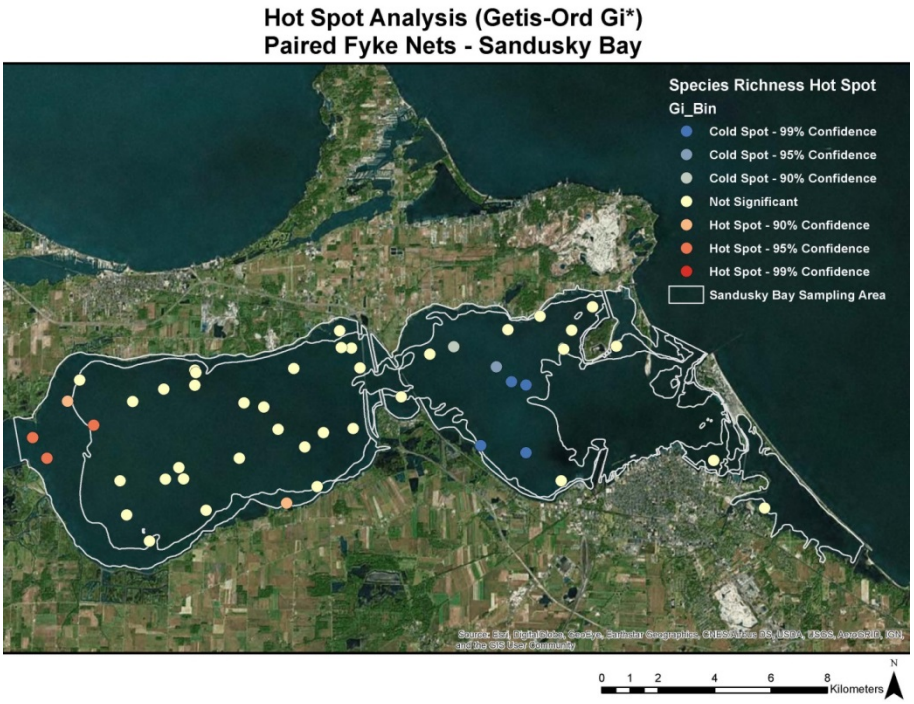


FIGURE C-12. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Sandusky Bay paired fyke nets using data collected from 2013-2016.

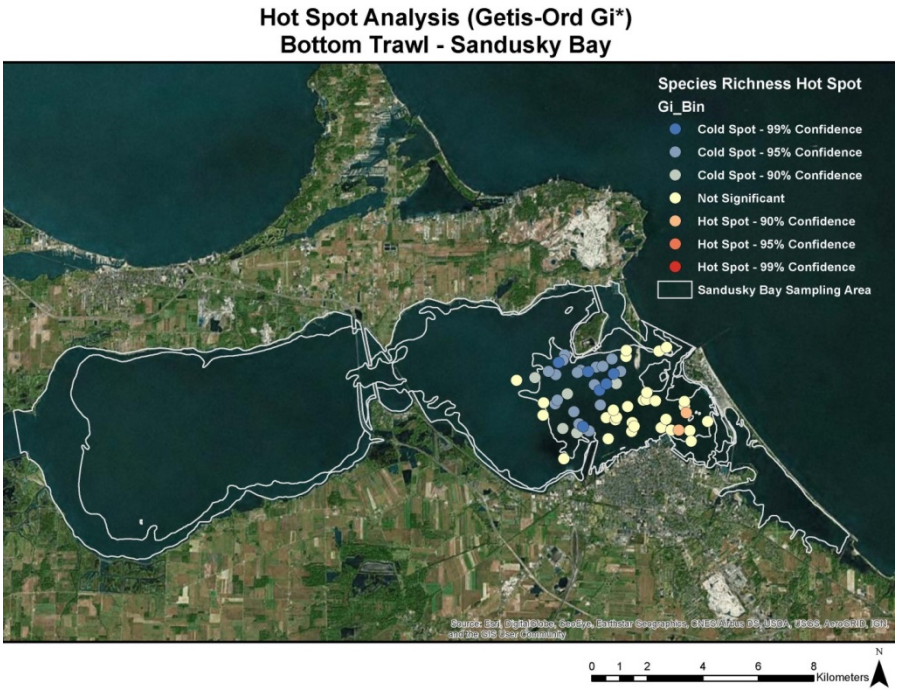


FIGURE C-13. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Sandusky Bay bottom trawls using data collected from 2013-2016.

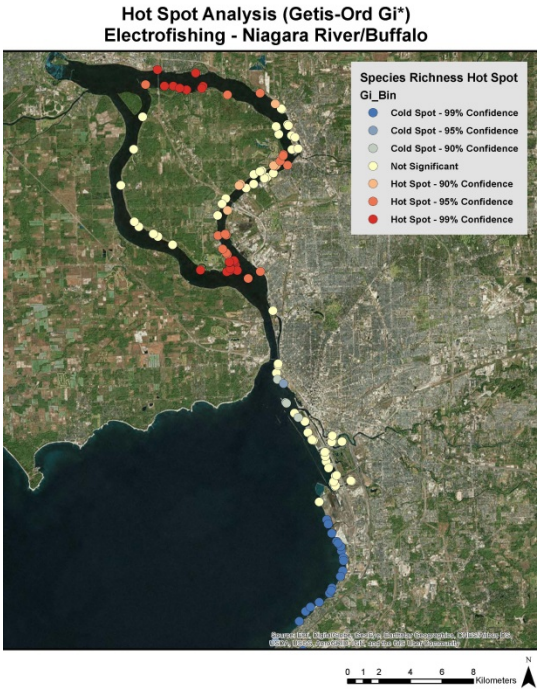


FIGURE C-14. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Buffalo/Upper Niagara River electrofishing using data collected from 2013-2016.

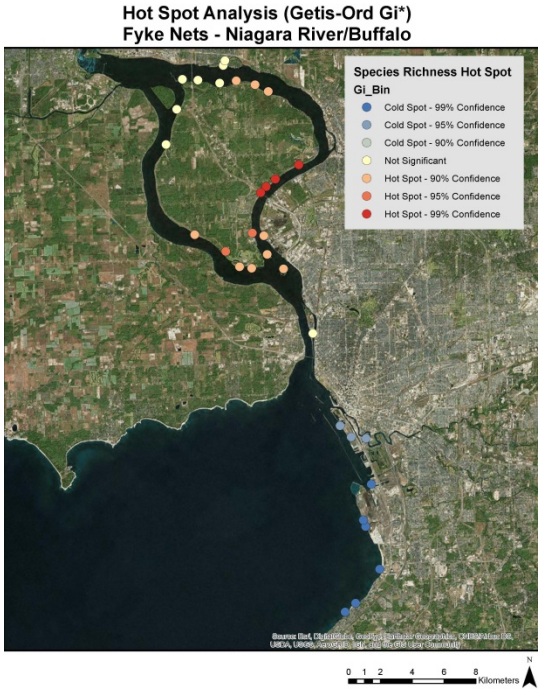


FIGURE C-15. Map depicting the results of Hot Spot Analysis (Getis-Ord Gi*) for Buffalo/Upper Niagara River paired fyke nets using data collected from 2013-2016.